85 | PROJECT REPORT

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Norges byggforskningsinstitutt

Einar M. Paulsen

Roofing systems with mechanical attachments

Results from testing with dynamic loading; test methods, backout classification and fastening design

Norwegian Building Research Institute 1991

Project Report 85

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ISBN 82-536-0367-3
800 copies printed by
Strindheim Trykkeri A/L

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Preface

Trondheim Division of the Norwegian Building Research Institute (NBI) has a specialised staff on building physics and climatic performance of buildings. An important function of the division is developing test methods and laboratory testing equipment. Another aspect is obtaining practical experience by investigating building faults and doing systematic field surveys.

This report summarises the laboratory testing and evaluation carried out at NBI as part of a Scandinavian project aimed at finding relevant methods of testing mechanically attached roofing systems for strength against the action of wind loads.

The work, which involves modification of apparatus, testing and reporting, has been funded by:

- the participating manufacturers

- Nordisk Industrifond
  (Nordic Fund for Technology and Industrial Development)

- Norges Teknisk-Naturvitenskapelige Forskningsråd (NTNF)
  (Royal Norwegian Council for Scientific and Industrial Research)

- Takprodusentenes Forskningsgruppe (TPF)
  (Norwegian Roofing Research Group)

Because of wide international interest and focus on wind-load testing of roofing membranes, the institute has decided to print this report in English.

Special thanks are extended to the following members of the laboratory staff at NBI Trondheim Division:

Aksel H. Olsen, designing and constructing the auxiliary equipment for testing dynamic loading,

Arne Bakkejord, for carrying out the laboratory testing.

Oslo/Trondheim May 1991

Åge Hallquist

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INTRODUCTION

The Trondheim Division of the Norwegian Building Research Institute (NBI) has been engaged in roofing research since its establishment in the 1950's.

For flat roofs with flexible roofing, field investigation techniques were originally used as a basis for subsequent revision of recommended codes of practice. At the beginning of the 1970's, the need for laboratory testing and evaluation became more evident. Backed by the industry, NBI set out to build a multi-function roof testing apparatus with test programmes for:

- wind uplift strength (pressure and temperature)
- simulated aging (temperature and moisture)
- accelerated aging (IR lamps and UV tubes)

The apparatus and the results of the initial research were presented at ISRR, Brighton in 1974.

During the 1970's, the apparatus was extensively used for wind- uplift strength research and commercial testing. The standard method for testing the wind-uplift strength of roof assemblies was proposed for adoption as a Nordtest Method and finally approved as NT BUILD 307 in 1986.

In 1987, NBI initiated a project with participants from the Scandinavian countries and cosupported by the Nordic Fund for Technology and Industrial Development to study the application of dynamic loading on mechanically attached roofing systems.

The first part was carried out in 1989 using single-ply polymeric membranes. Asphalt felt membranes were included in the last run in 1991 to cover the widest possible range of loosely applied, mechanically attached systems.

This report also includes the latest developments in strength testing of fasteners as well as design principles.

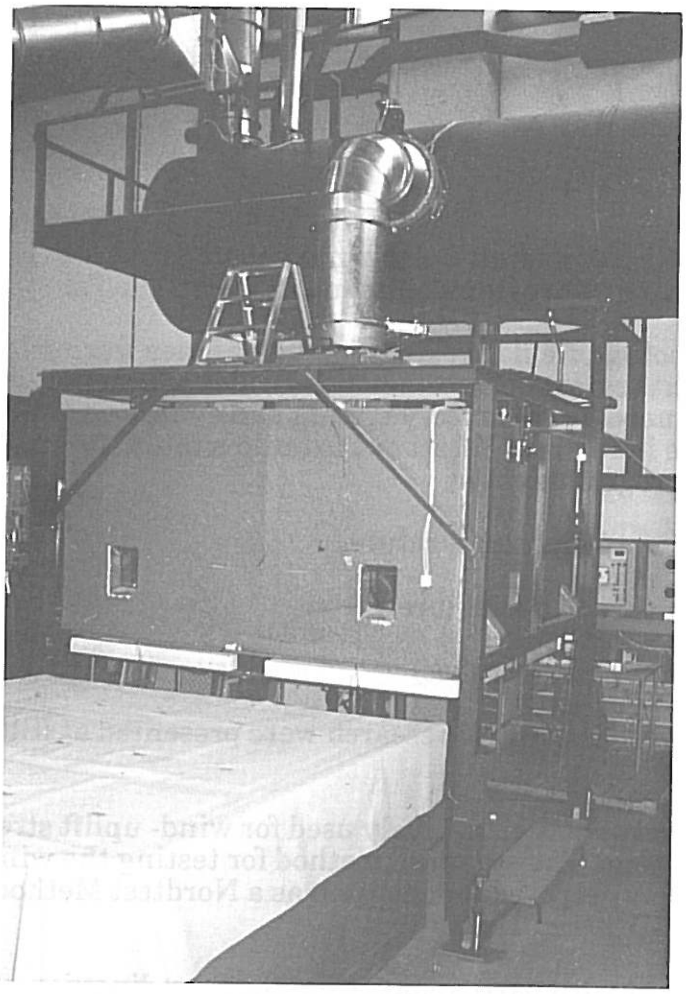


Photo 1
Roof testing
apparatus

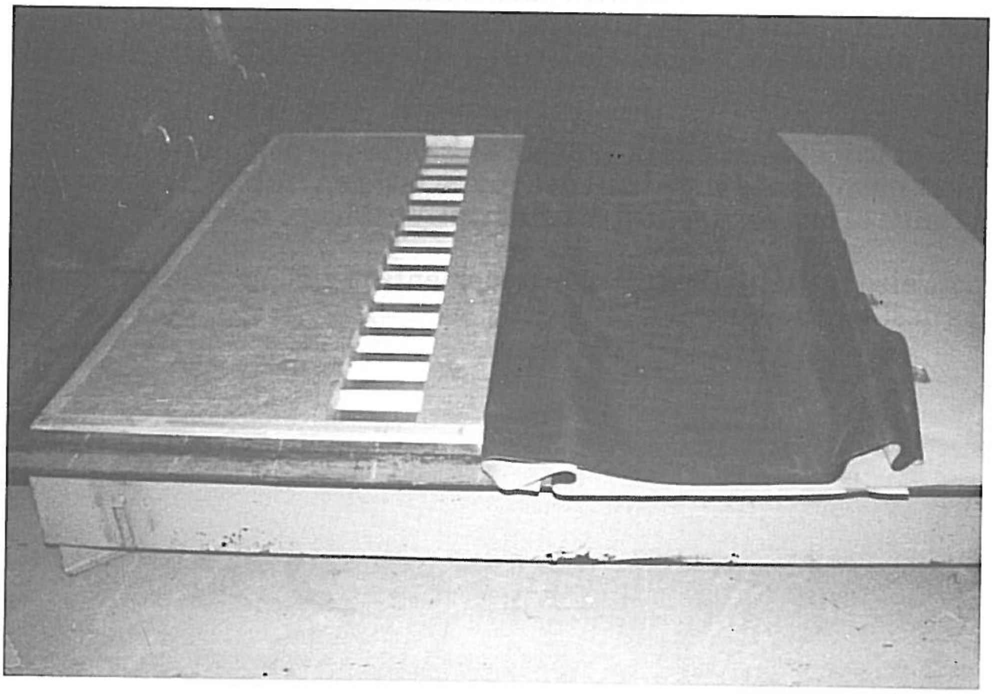


Photo 2
Test assembly with membrane and section without insulation

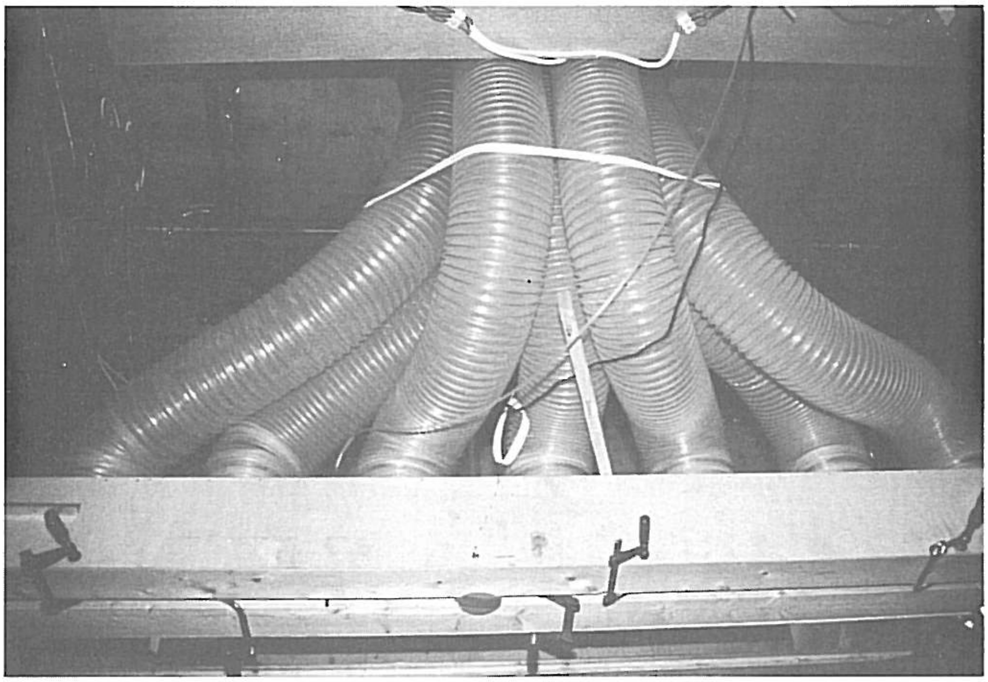


Photo 3
Air intake slit with flexible tubes

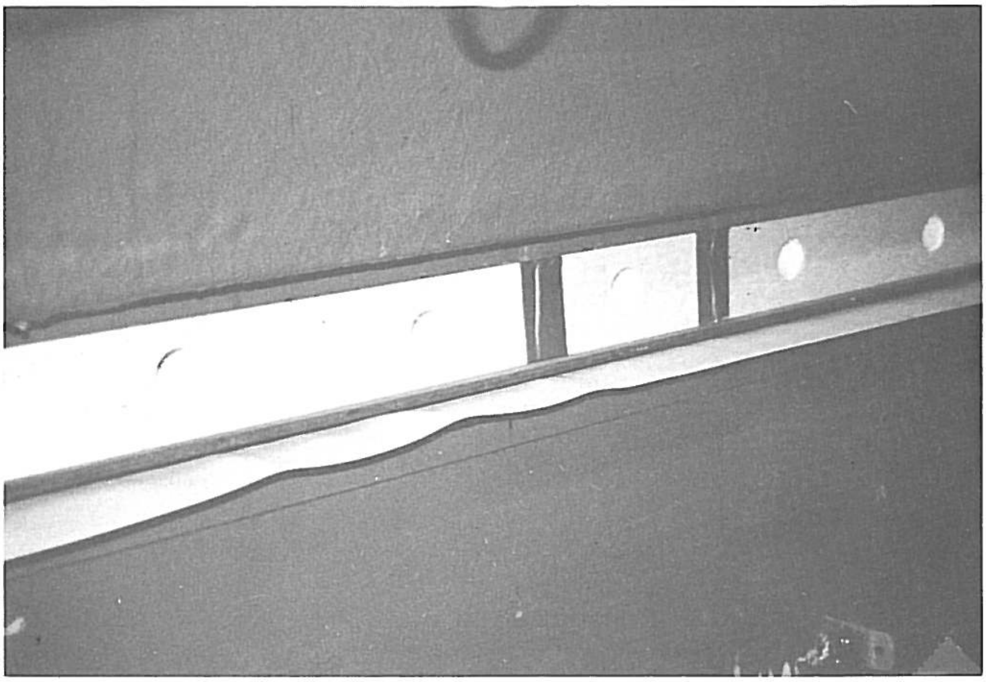


Photo 4
Holes to equalize pressure

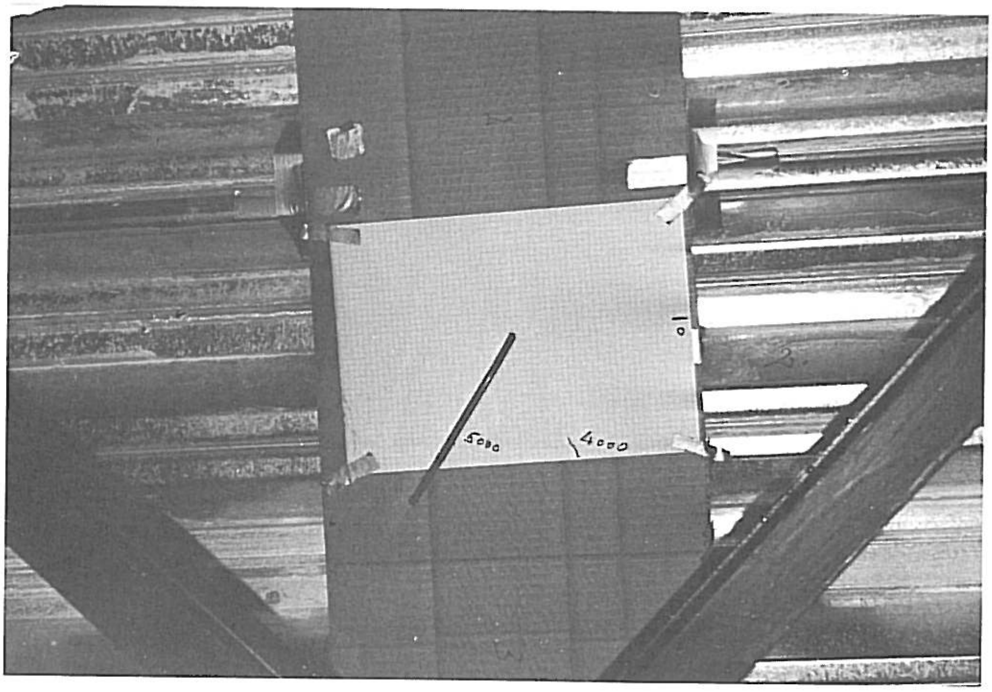


Photo 5
Indicator to record screw rotation

NORDIC PROJECT

The research involved in developing a method for applying dynamic loading to roofing assemblies was established as a project with participants representing Scandinavian countries, as follows:

Participants

Company	Country	Contact person
Fasteners		
Eigil Hørvid A/S	DK	Arne Collemorten
Jan Rube AB	S	Sven Appelros
SFS Stadler A/S	N	Roar Svendsen
Mustad Industrier A/S	N	Jan Erik Wold
Montasjeutstyr A/S	N	Bjørn Nordbotten
ITW Buildex	S	Conny Jondell
Markt & Co. A/S	N	Kjell Gullerud
Membrane and insulation		
Villadsens Fabrikker A/S	DK	Eigil Bech/Øystein Sjøtveit
Värnamo Isolerduk AB	S	Lars-Arne Lok
Protan A/S	N	Jon Hernæs
Isola as	N	Ola Tellesbø
Alkor Nordic K/S	DK	Peder Namensen/Arvid Juland
Rockwool AB	S	Claes-Göran Stadler
Elkem-Rockwool	N	Finn Rief
Support		
Verho Norge A/S	N	Jan Semundseth
Yxhult AB	S	Kjell Nygren
Siporex Elementbygg A/S	N	Jon Sundland

Reference group

The participants suggested that a reference group of five persons should be established. One representative from each of the above four sections of the building supply industry was elected and the chairman was appointed by NBI. The group has consisted of the following persons:

Nils Fjærvik, A.R. Reinertsen (Chairman)
Sven Appelros, Jan Rube AB (Fasteners)
Finn Rief, Elkem-Rockwool (Insulation)
Jan Semundseth, Verho Norge A/S (Support)
Harald Kittilsen, Isola as (Membrane)

WIND LOAD ASSEMBLY TEST

Apparatus and loading

Standard wind load (NT BUILD 307)

A section of the roof is placed in a steel frame and mounted between the upper and lower box. The membrane is held in position between the flanges of the steel frame and a steel profile surrounding the apparatus and is held down by the weight of the upper box.

Load is applied as static pressure in the lower box and pulsating suction in the upper box. Each load interval represents a testing time of 25 minutes with 5 minutes static load and 20 minutes pulsating load. The intensity of loading is increased in steps.

The temperature in the membrane can be controlled during testing using the air cooling arrangements. The recommended test temperatures are +40 °C, + 23 °C, ± 0 °C and −10 °C.

The mode of failure is determined on the basis of breakage of the membrane or fastening system, or any permanent deformation which may cause premature reduction in the service life of the waterproofing function of the membrane. The associated total load is given as the capacity of the assembly when failure takes place.

In the case of mechanically fixed systems, the design capacity is based on at least two assembly tests. Usually this means one assembly with relatively few fasteners and the other with a large number of fasteners. In this way, the major effects of fastener geometry and load increments are eliminated.

Dynamic loading (NBI 162/90)

The apparatus for applying dynamic wind load is shown in Fig. 1. It is basically the same as that used for testing with standard wind load, but with the following additions:

- a steel tank of 11 m^3 to store air at low pressure
- a 500 mm diameter release valve
- an air intake slit positioned between the rows of fasteners and connected to the main air duct by flexible tubes
- a 200 mm wide section without insulation in the roof assembly under the air intake slit and between rows of fasteners
- pressure equalizing between load applications

The load is applied as dynamic suction in a 30 mm wide slit positioned above the roof membrane and between the rows of fasteners where the insulation has been removed. The membrane under the air slit is lifted up first, resulting in a non-axial load being transmitted to the fasteners.

The following loading programmes have so far been defined and used in the research testing:

A Dynamic loading in intervals of increasing intensity.
Suction applied as gusts every 15 seconds for one hour per load interval. The intensity of the gust is increased in steps from one load interval to the other.

B Static + dynamic loading in intervals of increasing intensity.
Static suction is applied in the upper box to lift the membrane from the base. Gust intensity as in A.

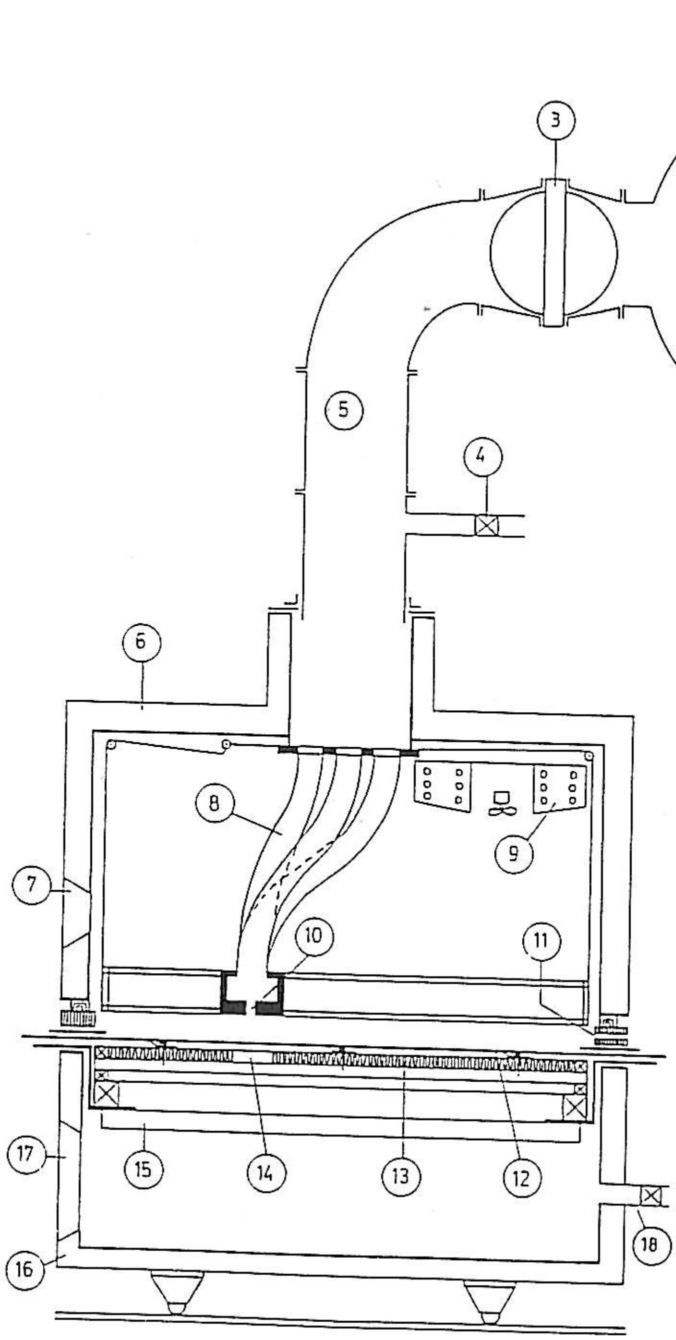
C Dynamic loading with fixed intensity.
Suction gusts applied continuously every 15 seconds, with fixed intensity.

The suction intensity quoted is instantaneous pressure measured at the air intake slit above the roof membrane.

Test conditions

The materials and membrane system to be used in the testing were selected on the basis of discussion within the reference group.

To keep track of all the different variables the following coding system is used.



1. Storage tank (11 m^3) for air at low pressure
2. Connection to fan for air evacuation
3. Valve to operate dynamic suction
4. Connection to fan operating pulsating suction for standard wind-load testing (NT BUILD 307)
5. Main air duct
6. Upper box
7. Inspection window
8. Flexible air tubes (7, with diam. 180 mm)
9. Air cooler
10. 30 mm air-intake slit
11. Holes to equalize pressure after gust
12. Roof membrane with fasteners
13. Roof deck with insulation
14. Section without insulation
15. Steel frame
16. Lower box
17. Inspection manhole
18. Connection to fan operating static pressure for standard wind-load testing (NT BUILD 307)

Fig. 1
Roof testing apparatus

Numbering of test assemblies

40/7-xx Assemblies with 0.7 mm profiled metal sheets having a height of 40 mm.

65/7-xx Assemblies with 0.7 mm profiled metal sheets having a height of 65 mm.

65/8-xx Assemblies with 0.8 mm profiled metal sheets having a height of 65 mm.

Insulation

EPS 50 50 mm expanded polystyrene with a density of 20 kg/m^3.

M 50 50 mm mineral wool with high compressive strength. Each insulation panel is fixed separately.

M 100 2 mm x 50 mm mineral wool with high compressive strength. Each insulation panel is fixed separately.

Membrane

T 1 1.2 mm PVC membrane with a core of PES fabric.

T 2 1.0 mm EPDM membrane with PES felt laminated to the lower side.

T 3 4.0 mm single-ply asphalt felt with slate granules on the top surface.

Location of fasteners

K At the edge of the 1 m wide membrane with a 130 mm overlap. Individual fasteners are 0.45 m apart and the space between each row is 0.87 m (c/c 0.45 m x 0.87 m = 2.55 per/m^2).

G Through the membrane. Individual fasteners are 0.45 m apart and the space between each row is 0.87 m (c/c 0.45 m x 0.87 m = 2.55 per/m^2).

O Through two plies in a 50 mm wide overlap. The joint is sealed with a hot air welded cover strip.

J In the joint between the 1 m wide membranes. The joint is sealed with a cover strip torch welded to the membrane. To eliminate the possibility of asphalt restricting any backout, the screw head is covered with aluminium foil. Individual fasteners are 0.45 mm apart and the space between each row is 1.0 m (c/c 0.45 m x 1.0 m = 2.22 per/m^2).

J 1 Same as J, but without aluminium foil. Before torch welding the cover strip, the stress plate is sprayed with water.

J 2 Same as J, but without aluminium foil. Torch welding is done under dry conditions.

Stress plates

F 1	Metal stress plate without recess (40 mm x 60 mm)
F 2	Metal stress plate without recess (40 mm x 82 mm)
F 3	Metal stress plate without recess (38 mm x 70 mm)
F 4	Metal stress plate without recess (40 mm x 80 mm)
F 5	Metal stress plate without recess (∅ 40 mm)
F 6	Plastic bracket with tube and stress plate (∅ 45 mm) in one piece
F 7	Metal stress plate without recess (∅ 40 mm)
F 8	Plastic bracket with tube and tagged stress plate (45 mm x 60 mm) in one piece
F 9	Metal stress plate with tags and without recess (60 mm x 95 mm).

Screws

S 1	Roofing screw with s point
S 2	Roofing screw with drill point
S 3	Roofing screw with s point
S 4	Roofing screw with x point
S 5	Roofing screw with drill point
S 6	Roofing screw with s point
S 7	Same as S 4, but with locking ribs under the head.

Pre-tensioning of fastener

Loose	The fastener is installed without pre-tensioning. Light pressure on the stress plate with two fingers makes the screw "come up" about 1 mm.
Tight	The fastener is installed with ordinary pre-tensioning.

Loading

After the test roof assembly has been installed in the apparatus, the following loading conditions for air pressure are used:

B 1	Dynamic suction from the storage tank is applied through a 30 mm wide slit positioned above the membrane and between the rows of fasteners where a 200 mm width of insulation has been removed. The membrane under the air slit is lifted up first, resulting in a non-axial load being transmitted to the fasteners.

Suction is applied as gusts every 15 seconds for one hour per load interval. The gust intensity is monitored by the pressure in the storage tank and is increased in steps of 1000 Pa (1000, 2000, 3000 Pa, etc.).

B 1 A Same as for B 1, but the gust intensity is monitored by pitot tube measurements at the air intake slit. The load is increased in steps of 200 Pa (200, 400, 600, 800 Pa, etc.).

B 1 A* Same as for B 1 A, but with the following membrane temperatures during testing:

−10 °C for load intervals 1, 2, 3, 4 and 5
± 0 °C for load intervals 6, 7, etc.

B 1 B Same as for B 1, but gusts have fixed intensity

B 2 Same as for B 1, but a static suction of 50 Pa is applied to lift the membrane.

B 3 Pulsating pressure test with stepwise increases in accordance with method NT BUILD 307.

B 4 Uniformly distributed static load.

Test assemblies

Test roofs with a profile height of 65 mm are listed in Table 1. Plate thicknesses of 0.7 mm and 0.8 mm were used.

Test roofs with a profile height of 40 mm are listed in Table 2. A plate thickness of 0.7 mm was the only one used.

Test results

Table 3 gives the order in which the individual test results from each assembly have been listed. For convenience, the results have been arranged in five groups, a - e, according to the main purpose of the test:

Group a: Initial testing with measurements of reaction transmitted to the fasteners

Group b: The effect of different loading conditions

Group c: The effect of variations in construction, such as deck stiffness, insulation thickness, location of fastener and type of screw

Group d: The effect of pre-tensioning on the fastener

Group e: Single-ply asphalt felt, where the effect of insulation thickness, type of screw and temperature influence was studied.

Table 1
Test assemblies with 65 mm profiled metal sheets

Assembly no.	Load	Insu-lation	Mem-brane	Location of fastener	Stress plate	Screw	Pre-tensioni
65/7-01	B 1	EPS 5	T 1	K	F 1	S 1	Loose
65/7-02	B 1	EPS 5	T 1	K	F 1	S 1	Loose
65/7-03	B 2	EPS 5	T 1	K	F 1	S 1	Loose
65/7-04	B 4	EPS 5	T 1	K	F 1	S 1	Loose
65/7-1	B 1	M 5	T 1	K	F 1	S 1	Loose
65/7-2	B 2	M 5	T 1	K	F 1	S 1	Loose
65/7-3	B 1 B	M 5	T 1	K	F 1	S 1	Loose
65/7-4	B 3	M 5	T 1	K	F 1	S 1	Loose
65/7-5	B 3	M 5	T 1	K	F 1	S 1	Loose
65/7-6	B 1	M 5	T 1	K	F 1	S 1	Loose
65/7-7	B 1	M 5	T 1	G	F 1	S 1	Loose
65/7-8	B 1	M 10	T 1	K	F 1	S 1	Loose
65/7-9	B 1	M 10	T 1	K	F 6	S 1	Loose
65/7-10	B 1 A	M 5	T 1	K	F 1	S 1	Loose
65/7-11	B 1 A	M 5	T 1	K	F 1	S 1	Tight
65/7-12	B 1 A	M 5	T 1	G	F 1	S 1	Loose
65/7-13	B 1 A	M 5	T 1	G	F 1	S 1	Tight
65/8-14	B 1 A	M 5	T 3	J	F 9	S 6	Loose
65/8-15	B 1 A*	M 5	T 3	J 1	F 9	S 6	Loose
65/8-16	B 1 A	M 5	T 3	J 2	F 9	S 6	Loose
65/8/17	B 1 A	M 5	T 3	J	F 9	S 3	Loose
65/8-18	B 1 A	M 5	T 3	J	F 9	S 4	Loose
65/8-19	B 1 A	M 10	T 3	J	F 9	S 6	Loose
65/8-20	B 1 A	M 10	T 3	J	F 9	S 3	Loose
65/8-21	B 1 A	M 10	T 3	J	F 9	S 4	Loose
65/8-22	B 1 A	M 5	T 3	J	F 9	S 2	Loose
65/8-23	B 1 A	M 10	T 3	J	F 4	S 7	Loose

le 2
; assemblies with 40 mm profiled metal sheets

embly no.	Load	Insulation	Mem-brane	Location of fastener	Stress plate	Screw	Pre-tensions
)/7 - 1	B 1	M 5	T 1	K	F 1	S 1	Loose
)/7 - 2	B 2	M 5	T 1	K	F 1	S 1	Loose
)/7 - 3	B 1 B	M 5	T 1	K	F 1	S 1	Loose
)/7 - 4	B 1	M 5	T 1	G	F 1	S 1	Loose
)/7 - 5	B 1	M 5	T 1	K	F 2	S 2	Loose
)/7 - 6	B 1	M 5	T 1	K	F 3	S 3	Loose
)/7 - 7	B 1	M 5	T 2	O	F 5	S 1	Loose
)/7 - 8	B 1	M 10	T 1	K	F 1	S 1	Loose
)/7 - 9	B 1	M 10	T 1	K	F 6	S 1	Loose
/7 - 10	B 1	M 10	T 1	G	F 1	S 1	Loose
/7 - 11	B 1	M 10	T 1	G	F 5	S 1	Loose
/7 - 12	B 1	M 5	T 1	G	F 4	S 4	Loose
/7 - 13	B 1 A	M 10	T 1	K	F 7	S 5	Loose
/7 - 14	B 1 A	M 10	T 1	K	F 8	S 1	Loose

Table 3
Test assemblies arranged in groups

Group	Assembly no.	Load	Insulation	Mem-brane	Location of fastener	Stress plate	Screw	Pr tensio
a	65/7-01	B 1	EPS 5	T 1	K	F 1	S 1	Loo
	65/7-02	B 1	EPS 5	T 1	K	F 1	S 1	Loo
	65/7-03	B 2	EPS 5	T 1	K	F 1	S 1	Loo
	65/7-04	B 4	EPS 5	T 1	K	F 1	S 1	Loo
b	65/7-1	B 1	M 5	T 1	K	F 1	S 1	Loo
	65/7-2	B 2	M 5	T 1	K	F 1	S 1	Loo
	40/7 - 1	B 1	M 5	T 1	K	F 1	S 1	Loo
	40/7 - 2	B 2	M 5	T 1	K	F 1	S 1	Loo
	65/7-3	B 1 B	M 5	T 1	K	F 1	S 1	Loo
	40/7 - 3	B 1 B	M 5	T 1	K	F 1	S 1	Loo
	65/7-4	B 3	M 5	T 1	K	F 1	S 1	Loo
	65/7-5	B 3 *	M 5	T 1	K	F 1	S 1	Loo
c	65/7-6	B 1	M 5	T 1	K	F 1	S 1	Loo
	65/7-7	B 1	M 5	T 1	G	F 1	S 1	Loo
	40/7 - 4	B 1	M 5	T 1	G	F 1	S 1	Loo
	40/7 - 12	B 1	M 5	T 1	G	F 4	S 4	Loo
	40/7 - 5	B 1	M 5	T 1	K	F 2	S 2	Loc
	40/7 - 6	B 1	M 5	T 1	K	F 3	S 3	Loo
	40/7 - 7	B 1	M 5	T 2	O	F 5	S 1	Loc
	65/7-8	B 1	M 10	T 1	K	F 1	S 1	Loc
	65/7-9	B 1	M 10	T 1	K	F 6	S 1	Loo
	40/7 - 8	B 1	M 10	T 1	K	F 1	S 1	Loo
	40/7 - 9	B 1	M 10	T 1	K	F 6	S 1	Loc
	40/7 - 10	B 1	M 10	T 1	G	F 1	S 1	Loc
	40/7 - 11	B 1	M 10	T 1	G	F 5	S 1	Loc
d	65/7-10	B 1 A	M 5	T 1	K	F 1	S 1	Loc
	65/7-11	B 1 A	M 5	T 1	K	F 1	S 1	Tig
	65/7-12	B 1 A	M 5	T 1	G	F 1	S 1	Loc
	65/7-13	B 1 A	M 5	T 1	G	F 1	S 1	Tig
	40/7 - 13	B 1 A	M 10	T 1	K	F 7	S 5	Loc
	40/7 - 14	B 1 A	M 10	T 1	K	F 8	S 1	Loc

ble 3 (cont.)
st assemblies arranged in groups

roup	Assembly no.	Load	Insulation	Mem-brane	Location of fastener	Stress plate	Screw	Pre-tensioning
	65/8-14	B 1 A	M 5	T 3	J	F 9	S 6	Loose
	65/8-15	B 1 A *	M 5	T 3	J 1	F 9	S 6	Loose
	65/8-16	B 1 A	M 5	T 3	J 2	F 9	S 6	Loose
e	65/8-17	B 1 A	M 5	T 3	J	F 9	S 3	Loose
	65/8-18	B 1 A	M 5	T 3	J	F 9	S 4	Loose
	65/8-19	B 1 A	M 10	T 3	J	F 9	S 6	Loose
	65/8-20	B 1 A	M 10	T 3	J	F 9	S 3	Loose
	65/8-21	B 1 A	M 10	T 3	J	F 9	S 4	Loose
	65/8-22	B 1 A	M 5	T 3	J	F 9	S 2	Loose
	65/8-23	B 1 A	M 10	T 3	J	F 4	S 7	Loose

Assembly no. 65/7-01

Load:	B 1	Stress plate:	F 1
Insulation:	EPS 5 (not fixed)	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Load on fastener
Pa	Pa	N
1000		
2000	280	100
3000	500	150
4000	640	220
5000	960	280

Comments: Tearing around stem

Assembly no. 65/7-02

Load:	B 1	Stress plate:	F 1
Insulation:	EPS 5 (fixed)	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Load on fastener
Pa	Pa	N
1000	170	20
2000	350	70
3000	520	120
4000	740	200
5000	920	280

Comments: Testing stopped

Assembly no. 65/7-03

Load: B 2
Insulation: EPS 5 (fixed)
Membrane: T 1
Location of fastener: K

Stress plate: F 1
Screw: S 1
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Load on fastener
Pa	Pa	N
1000		
2000		
3000	540	180
4000		
5000	910	300

Comments: Testing stopped

Assembly no. 65/7-04

Load: B 4
Insulation: EPS 5 (not fixed)
Membrane: T 1
Location of fastener: K

Stress plate: F 1
Screw: S 1
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Load on fastener
Pa	Pa	N
500	500	240
1000	1000	400
500	500	250

Comments: Testing stopped

Assembly no. 65/7-1

Load:	B 1	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	180					
2000	320					
3000	550					
4000	780					
5000	980			0		
6000	1300	0	0	3	0	
7000	1550	2	2	5	2	0

Comments: Tearing around stem

Assembly no. 65/7-2

Load:	B 2	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	300					
2000	580					
3000	980					
4000	1200					
5000	1450	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 40/7-1

Load:	B 1	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	180					
2000	350			0	0	
3000	560		0	3	4	
4000	780		14	6	7	0
5000	980		25	5	60	3
6000	1180	0	30	- 36	76	15
7000	1450					

Comments: Tearing around stem

Assembly no. 40/7-2

Load:	B 2	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	260		0		0	
2000	500		7		3	
3000	820		8		6	
4000	1100	−3	8		6	
5000	1400	−10	9		10	0
6000	1700	−5	10	0	11	3

Comments: Tearing around stem

Assembly no. 65/7-3

Load:	B 1 B (4000/800 Pa)	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Testing time	Rotation of screw no. (Deg.)				
h	1	2	3	4	5
1					
2					
3		3		3	
4					
5				11	
6				13	
7				16	
8				20	
9				27	
10				32	
11				35	
12					
13				44	
14					
15					
16					
17		–11			
18		–16			
19					
20	–8	–20	10	66	0

Comments: Tearing around stem

Assembly no. 40/7 - 3

Load:	B 1 B (4000/800 Pa)	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Testing time	Rotation of screw no. (Deg.)				
h	1	2	3	4	5
1		0			
2		96			
3					
4		107			
5		107			
6	0	107	0	0	0

Comments: Tearing around stem

Assembly no. 65/7 - 4

Load:	B3 (NBI 92/85)	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K	Temp. in membrane:	+23 °C

Static load	Bulging of membrane under static load	Total load
Pa	mm	Pa
0	0	0
500	90	700
1000	110	1400

Comments: Tearing around stem

Capacity at break per fastener: $\frac{1400}{2.55}$ = 549 N per fastener

Assembly no. 65/7 - 5

Load:	B3 (NBI 92/85)	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K	Temp. in membrane:	±0 °C

Static load	Bulging of membrane under static load	Total load
Pa	mm	Pa
0	0	0
500	90	700
1000	120	1400

Comments: Tearing around stem

Capacity at break per fastener: $\frac{1400}{2.55}$ = 549 N per fastener

Assembly no. 65/7 - 6

Load:	B 1	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	160					
2000	330					
3000	540					
4000	800				0	
5000	1100				16	
6000	1300	0	0	0	19	0

Comments: Tearing around stem

Assembly no. 65/7 - 7

Load:	B 1	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	G		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	170					
2000	380		0	0		
3000	580		4	18	0	
4000	890		37	152	–22	
5000	1230	0	127	1+144	–55	
6000	1450	22	253	2+271	–110	
7000	1800	43	1+264	4+348	–125	0

Comments: Testing stopped

Assembly no. 40/7 - 4

Load:	B 1	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	G		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	150		0	0	0	
2000	400		5	10	7	
3000	600		26	54	24	
4000	820	0	108	232	60	
5000	1080	15	244	1+99	85	
6000	1440	65	1+55	1+355	105	
7000	1750	145	1+80	2+150	226	0

Comments: Testing stopped

Assembly no. 40/7 - 12

Load:	B 1	Stress plate:	F 4
Insulation:	M 5	Screw:	S 4
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	G		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	200		0	7		
2000	390	0	8	64	0	
3000	600	15	53	67	2	
4000	820	28	60	78	3	0
5000	1120	21	70	117	14	5
6000	1460		76	128	35	37
7000	1740	8	72	276	170	52

Comments: Testing stopped

Assembly no. 40/7 - 5

Load: B 1
Insulation: M 5
Membrane: T 1
Location of fastener: K

Stress plate: F 2
Screw: S 2
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	180					
2000	410					
3000	600			0	0	
4000	780		0	5	−8	
5000	1000	0	−11	25	−9	0

Comments: Tearing around stem

Assembly no. 40/7 - 6

Load: B 1
Insulation: M 5
Membrane: T 1
Location of fastener: K

Stress plate: F 3
Screw: S 3
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	200					
2000	380				0	
3000	570		0		−7	
4000	820		7		−10	
5000	970		9		−23	
6000	1150	0	10	0	−15	0

Comments: Tearing around stem

Assembly no. 40/7 - 7

Load: B 1
Insulation: M 5
Membrane: T 2
Location of fastener: O

Stress plate: F 5
Screw: S 1
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	180		0			
2000	350		80		0	
3000	540		175	0	5	
4000	740		171	4	23	
5000	880	0	150	6	108	
6000	1200	3	132	6	229	
7000	1400	56	34	171	1 + 29	0

Comments: Tearing around stress plate

Assembly no. 65/7 - 8

Load: B 1
Insulation: M 10
Membrane: T 1
Location of fastener: K

Stress plate: F 1
Screw: S 1
Pre-tensioning: Loose

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	160					
2000	350					
3000	580					
4000	850					
5000	1120					
6000	1440					
7000	1600	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 65/7 - 9

Load:	B 1	Stress plate:	F 6
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	160					
2000	350					
3000	570					
4000	800					
5000	1050					
6000	1320					
7000	1530					
8000	1730	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 40/7 - 8

Load:	B 1	Stress plate:	F 1
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	200					
2000	400					
3000	650					
4000	900					
5000	1100	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 40/7 - 9

Load:	B 1	Stress plate:	F 6
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	210					
2000	400					
3000	600					
4000	840					
5000	1100					
6000	1300	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 40/7 - 10

Load:	B 1	Stress plate:	F 1
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	G		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	200					
2000	400					
3000	630					
4000	850			0	0	
5000	1130		0	3	23	
6000	1400	0	4	58	48	
7000	1700	10	13	96	76	0

Comments: Testing stopped

Assembly no. 40/7 - 11

Load:	B 1	Stress plate:	F 5
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	G		

Vacuum on tank	Suction in slit	Rotation of screw no. (Deg.)				
Pa	Pa	1	2	3	4	5
1000	200					
2000	400					
3000	600					
4000	850					
5000	1080		0	0	0	
6000	1500	0	26	5	38	
7000	1700	34	147	38	150	0

Comments: Testing stopped

Assembly no. 65/7 - 10

Load:	B 1 A	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600					
4	800					
5	1000					
6	1200	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 65/7 - 11

Load:	B 1 A	Stress plate:	F 1
Insulation:	M 5	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Tight
Location of fastener:	K		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600					
4	800					
5	1000					
6	1200					
7	1400	0	0	0	0	0

Comments: Tearing around stem

Assembly no. 65/7 - 12

Load: B 1 A   Stress plate: F 1
Insulation: M 5   Screw: S 1
Membrane: T 1   Pre-tensioning: Loose
Location of fastener: G

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200			0	0	
2	400		0	9	17	
3	600	0	6	11	33	
4	800	12	15		45	
5	1000	21	31		51	0
6	1200	37	61			12
7	1400	54				21
8	1600	73		−27	60	60
9	1800	110	66	−57	−15	120

Comments: Testing stopped

Assembly no. 65/7 - 13

Load: B 1 A   Stress plate: F 1
Insulation: M 5   Screw: S 1
Membrane: T 1   Pre-tensioning: Tight
Location of fastener: G

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600					
4	800					
5	1000			0		
6	1200	0	0	12	0	
7	1400	6	10	22	3	
8	1600	11	15	28	8	
9	1800	17	27	32	29	0

Comments: Testing stopped

Assembly no. 40/7 - 13

Load:	B 1 A	Stress plate:	F 7
Insulation:	M 10	Screw:	S 5
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600					
4	800					
5	1000				0	
6	1200			0	8	
7	1400			7	7	
8	1600	0	0	7	32	0

Comments: Tearing at stress plate

Assembly no. 40/7 - 14

Load:	B 1 A	Stress plate:	F 8
Insulation:	M 10	Screw:	S 1
Membrane:	T 1	Pre-tensioning:	Loose
Location of fastener:	K		

Load		Rotation of screw no. (Deg)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400		0			
3	600		18			
4	800		30			
5	1000		45	0	0	
6	1200		62	22	4	0
7	1400	0	86	82	11	35
8	1600	16	135	165	75	78
9	1800	21	197	258	192	122

Comments: Testing stopped; watertightness of membrane damaged

Assembly no. 65/8 - 14

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 5	Screw:	S 6
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200		0		0	
2	400		5	0	45	
3	600		25	37	248	0
4	800		73	346	1+320	16
5	1000		152	1+210	2+173	104
6	1200	0	285	3+347 1)	4+155 2)	220

Comments:
1) Rotation indicator stopped against metal sheet
2) Rotation indicator fell off

Assembly no. 65/8 - 15

Load:	B 1 A*	Stress plate:	F 9
Insulation:	M 5	Screw:	S 6
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J 1		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400		0	0	0	
3	600		3	10	10	
4	800		5	35	40	0
5	1000		10	85	160	10
6	1200		-	190	245	25
7	1400		90	310	1+30	90
8	1600		1+50	1+225	1+205	1+95
9	1800	0	2+85	2+45	2+330	2+140

Comments: Testing stopped

* Temperature in membrane during testing was:
−10 °C for load interval 1 to 5
± 0 °C for load interval 6 to 9

Assembly no. 65/8 - 16

Load: B 1 A
Insulation: M 5
Membrane: T 3
Location of fastener: J 2

Stress plate: F 9
Screw: S 6
Pre-tensioning: Loose

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200				0	
2	400				10	
3	600		0	0	40	
4	800		10	20	100	0
5	1000		30	160	310	20
6	1200		45	1+80	1+345	60
7	1400		100	1+290	2+230	190
8	1600	0	-	2+5	4+290 1)	1+120

Comments: Testing stopped
1) Rotation indicator stopped against metal sheet

Assembly no. 65/8 - 17

Load: B 1 A
Insulation: M 5
Membrane: T 3
Location of fastener: J

Stress plate: F 9
Screw: S 3
Pre-tensioning: Loose

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200			0	0	
2	400			10	90	0
3	600			30	170	7
4	800			50	215	60
5	1000			90	240	100
6	1200			310	1+280	140
7	1400			1 + 320	2+70	220
8	1600			2+340	2+210	240
9	1800		0	3+90	3+10	340
10	2000	0	30	3+260	3+20	1+190

Comments: Testing stopped

Assembly no. 65/8 - 18

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 5	Screw:	S 4
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200				0	
2	400		0	0	20	
3	600		10	5	100	0
4	800		15	20	100	10
5	1000		35	40	100	20
6	1200		60	50	100	40
7	1400		120	50	100	270
8	1600		135	50	100	1+60
9	1800		140	85	300	2+30
10	2000	0	210	230	260	3+90

Comments: Testing stopped

Assembly no. 65/8 - 19

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 10	Screw:	S 6
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200		0			
2	400	0	20	0	0	
3	600	35	85	10	40	
4	800	65	250	35	100	
5	1000	110	1+230	170	160	0
6	1200	170	2+95	320	280	20
7	1400	220	4+310	1+170	1+160	30
8	1600	260	1)	2+90	1+350	40

Comments: 1) Backout of screw from metal sheet

Assembly no. 65/8 - 20

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 10	Screw:	S 3
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400	0	0	0		
3	600	10	10	45		
4	800	20	40	90		
5	1000	30	80	140	0	
6	1200	40	120	180	40	0
7	1400	40	170	340	120	10
8	1600	-	200	1+270	190	20
9	1800	-	240	2+290	350	-
10	2000	340	-	3+120	1+130	50

Comments: Testing stopped

Assembly no. 65/8 - 21

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 10	Screw:	S 4
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200		0	0		
2	400		30	15	0	
3	600		40	20	20	
4	800		100	50	30	0
5	1000		180	1+15	150	10
6	1200		1+90	1+340	250	20
7	1400	0	1+140	2+90	1+240	30
8	1600	320	1+280	2+150	2+140	40
9	1800	-	2+20	2+170	2+180	110
10	2000	360	2+110	2+350	2+250	120

Comments: Testing stopped

Assembly no. 65/8 - 22

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 5	Screw:	S 2
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600		0	0		
4	800		30	20		
5	1000	0	40	30	0	0
6	1200	10	130	40	30	10
7	1400	20	160	110	60	20
8	1600	30	160	120	90	30
9	1800	40	170	130	100	30
10	2000	1)	1)	1)	1)	90

Comments: 1) Pullout of screw from metal sheet

Assembly no. 65/8 - 23

Load:	B 1 A	Stress plate:	F 9
Insulation:	M 5	Screw:	S 2
Membrane:	T 3	Pre-tensioning:	Loose
Location of fastener:	J		

Load		Rotation of screw no. (Deg.)				
Interval	Suction in slit Pa	1	2	3	4	5
1	200					
2	400					
3	600					
4	800					
5	1000					
6	1200					
7	1400					
8	1600	0	0	0	0	0

Comments: 1) Bending of stress plate and pull through in membrane

DISCUSSION OF RESULTS

Group a:

Assembly nos.: 65/7-01, 65/7-02, 65/7-03, 65/7-04

Initial testing to study the performance of the apparatus with respect to loading conditions and reaction to the test assembly. Deformation of the metal sheet deck, load on the fastener and air pressure were recorded during the testing.

A section of the chart is reproduced in Fig. 2 for the two situations where the insulation panels are fixed separately and not fixed.

The recordings of pressure and deformation for these two situations are identical, but the loads transmitted to the points where the fastener is attached to the metal sheet are different.

When the insulation panels are "loose" they are lifted up by the instantaneous pressure against the stress plate, causing a load on the fastener which is also the membrane attachment.

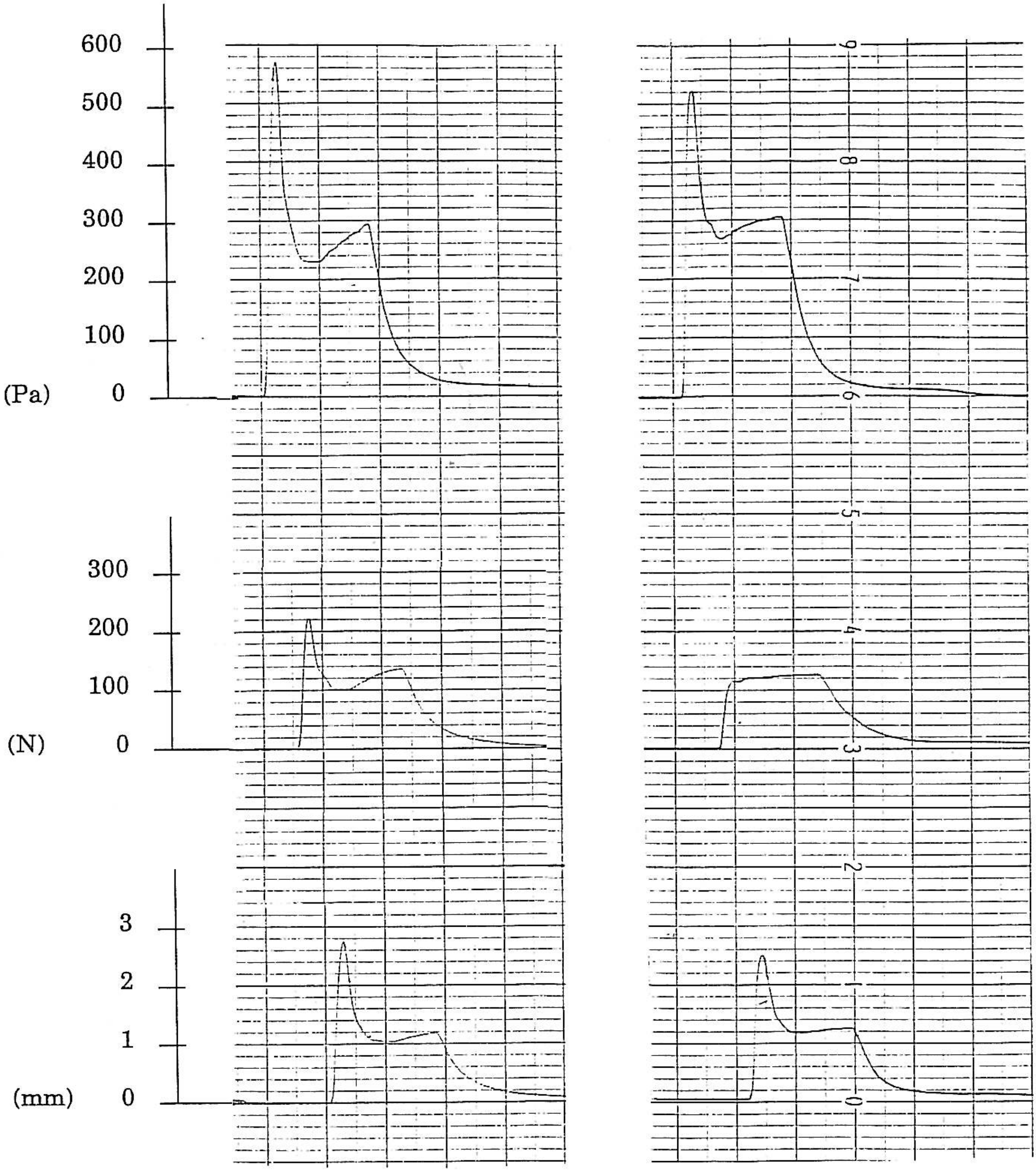
Separate fixing of the insulation panels makes them stay in place and no load is put on the fastener before the membrane has had time to move from an absolutely flat position to a raised one where the load is transmitted to the stress plate. Movement of the membrane also depends on how airtight the substructure is. The substructure under the air intake slit, where insulation is lacking, is more pervious than the other side of the rows of fasteners. This results in one side moving upwards before the other, initiating a lateral movement to the top of the fastener. Simultaneously, there is a non-axial upward pull on the fastener by the membrane. In the middle part of the cycle, this pull becomes a centric or an eccentric force depending on how the stress plate is attached to the membrane.

As a result of these measurements, it was decided to fix the insulation panels separately for all subsequent testing. The basic reasons for this were the need to know the exact test condition and to achieve increased reproducibility from one run to the other.

The actual load transmitted to the fastener varies with the type of loading. With dynamic loading (B 1), as in Fig. 2, there is good correlation between the average maximum air pressure in the box (300 Pa) and the recorded load on the fastener (120 Pa). 2.55 fasteners per m^2 give a theoretical value of 117 N.

Static loading (B 4) has best correlation at 1000 Pa (1000 Pa : 2.55 per m^2 = 392 N).

When dynamic loading (B 1) is compared with static (50 Pa) + dynamic loading (B 2), the difference measured at a slit pressure of about 500 Pa is seen to be 60 Pa. At a slit pressure of 900 Pa, the difference is no more than 20 Pa.



a) Insulation not fixed   b) Insulation fixed

Fig. 2
Recordings of measurements during testing using 3000 Pa negative pressure on tank

- air pressure in slit (Pa)
- load transmitted to fastener (N)
- deformation of metal sheets (mm)

Group b:

Assembly nos.: *65/7-1, 65/7-2, 40/7-1, 40/7-2,*
65/7-3, 40/7-3, 65/7-4, 65/7-5.

The main objective in this section was to study different loading conditions. With the exception of the deck stiffness all the construction factors were the same.

Comparing the load conditions, dynamic (B 1), and static + dynamic (B 2), shows that the backout of the screws is slightly higher using B 1 than B 2. There is also a tendency of higher rotation on 40 mm deck than on 65 mm deck.

The capacity at break gives more load intervals for B 1 than B 2. This should indicate that when lifting up the membrane first, the dynamic suction has a more severe attack on the strength of fastening to membrane.

Dynamic load with fixed intensity (B 1 B) was used twice with pressures for tank and slit, 4000 Pa and 800 Pa respectively. The screws showed scattered rotation. The testing time before failure was 20 h for 65 mm and only 6 h for 40 mm. The large difference could not be explained and contributed to the decission not to persue this type of loading further.

Pulsating load (B 3) according to method NBI 92/85 (NT BUILD 307), Appendix B, was used with test temperature at ambient temperature (+23 °C) and at ±0 °C. The capacity at break is unchanged for membrane T 1 due to change in temperature. The load at break was 1400 Pa, which is in the same magnitude as the dynamic slit pressure measured using B 1 in assembly 65/7-1 and 40/7-1.

Group c:

Assembly nos.: *65/7-6, 65/7-7, 40/7-4, 40/7-12*
40/7-5, 40/7-6, 40/7-7,
65/7-8, 65/7-9, 40/7-8, 40/7-9,
40/7-10, 40/7-11

The variables studied in this part have been deck stiffness, insulation thickness, type of screw and location of fastening point in membrane.

From the data available there is no clear indication that the deck stiffness have any noticable effect on the screw rotation.

Fastener installed at edge gives hardly any rotation before tearing out around the stem. Fastener installed through membrane have highest rotation at 50 mm insulation thickness and noticable less when the insulation is 100 mm.

Group d:

Assembly nos.: 65/7-10, 65/7-11, 65/7-12,
65/7-13, 40/7-13, 40/7-14

The pre-tensioning of fasteners described as "loose" or "tight" was investigated against variables such as insulation thickness and whether the fastener is located at the edge or through the membrane.

So far, loading has been regulated by keeping the air pressure of the tank at fixed levels of 1000 Pa, 2000 Pa, etc. Reproducibility has been improved by using the instantaneous pressure at the air intake slit as an indicator, with intervals of 200 Pa (200 Pa, 400 Pa, 600 Pa, etc.).

When fasteners are installed at the edge, the strength when failure occurs is improved using "tight" installation. When they are installed through the membrane, rotation is delayed with "tight" installation.

Group e:

Assembly nos.: 65/8-14, 65/8-15, 65/8-16,
65/8-17, 65/8-18, 65/8-19,
65/8-20, 65/8-21, 65/8-22,
65/8-23

Loosely applied, spot-fixed asphalt felt can in principle be compared with a mechanically attached, polymeric membrane system. The basic difference is the mass of the membrane. The single-ply asphalt membrane surfaced with stone-chippings used in this part of the test is about three times heavier than the polymeric membrane T 1 used in the first part of this research project.

The influence of temperature, insulation thickness and type of screw are the main variables studied here.

When installation took place, the row of fasteners was covered by torch bonding the cover strip on top of the stress plate. In this process, asphalt usually comes into contact with the screw head. But the test has shown that this cannot be relied upon to prevent rotation of the screw. Even when installed perfectly, the screw rotates once the bond from the asphalt has been broken. Water on the screw head and low temperatures caused rotation to start sooner. But as soon as the bond was broken, screw rotation was similar to when aluminium foil covered the screw head.

The results in this section of the test do not indicate that screw rotation is different for 50 mm or 100 mm insulation.

Two factors were found to reduce backout. One was where the cutting edge of the drill point of the screw had a smaller diameter than the bottom of the threads, and the other where diagonal ribs had been placed under the screw head in contact with the stress plate.

Three types of failure were recorded:

- total backout of the screw from the metal sheet
- pullout of the screw from the metal sheet
- bending of the stress plate and pull through in the membrane

Safeguarding against backout

On the basis of the test results and discussion in the previous sections, a classification of ways of safeguarding against backout of self-tapping and self-drilling screws used as roofing fasteners on profiled metal sheet decks has been worked out.

The four categories presented are based on assembly tests employing method NBI 162/90 (Appendix C) and using dynamic loading (A) or static + dynamic loading (B) with the following test conditions:

- a profiled metal sheet deck with .8 mm thick plates and a profile height of 65 mm
- 100 mm mineral wool insulation with the panels fixed separately to the deck
- the membrane should be single ply and fastened with three rows of fasteners with five fasteners in each row
- the fasteners should be installed with pre-tensioning characterized as "loose"
- factors reducing screw rotation, but which cannot be relied upon, should be omitted during testing (e.g. asphalt on top of the screw)
- after testing to failure or to load interval 10, screws should have rotated less than one revolution (360 degrees).

The following letter coding has been used to define the categories:

G = general usage
R = reduced load
T = through membrane
S = system dependent
F = flap or edge installation
A = dynamic loading NBI 162/90
B = static + dynamic loading NBI 162/90

GTA This is intended to represent the worst possible condition. The fastener is installed through the membrane or in such a manner that under static air pressure loading a centric axial pull will be transmitted to the deck. The stress plate is of metal without any recess. The screw head has no special device to hinder rotation.

A screw in this category can be used in all the other combinations.

GSA The fixing system must be looked upon as one unit where either the stress plate or the screw has an anti-rotation device.

GFA The most common way of fixing polymeric sheets is to locate the fastener at the edge of the membrane. Testing has shown that this is not the most critical condition as regards backout.The air flow is considerably retarded when the insulation is in two overlapping layers. This, combined with the extreme stiffness of the metal sheet deck, may explain the relatively few cases of backout so far recorded in Scandinavia.

RB In this case, the construction is such that the effect of the dynamic external wind suction is reduced when the load is transmitted to the fastener. This requires an aircheck for new roofs, but in re-roofing the old membrane has this function.

The categories and conditions related to loading, location of fastener, type of fastener and usage are summarized in Table 4.

Table 4
A classification system showing ways of safeguarding against backout of self-tapping and self-drilling screws

Conditions	Category			
	GTA	GSA	GFA	RB
Loading	NBI 162/90 Dynamic A	NBI 162/90 Dynamic A	NBI 162/90 Dynamic A	NBI 162/90 Stat. + Dyn. B
Location of fastener	Through membrane c/c 1.0 m	Through membrane c/c 1.0 m	At edge or in flap c/c 0.87 m	Through membrane c/c 1.0 m
Fastener type	Metal stress plate	Fastening system	Metal stress plate	Metal stress plate
Usage	Screw can be used in all combinations	Fastening system must be considered as one unit	Fastener installed at edge or in flap	Extra air check is required

SIMPLIFIED MEMBRANE TEST (Method NBI 163/91) (Appendix D)

NBI has developed a method for assessing the pull-through resistance in membrane using cumulative loading for:

- clout nails with up to 20 mm diameter heads where the membrane is fixed between metal rings with an internal diameter of 125 mm.
- mechanical fasteners with stress plates > 20 mm and where the membrane is fixed to a nail-studded metal frame measuring 400 mm by 400 mm.

The fastener can be installed in two ways

a) through the membrane (Photo 6)

b) through an underlying flap or the membrane edge and pre-tensioned against a piece of insulation (Photo 7).

The pull-through strength is determined in a tensile testing machine using a constant deformation speed of 50 mm/min.

The correlation between capacity at failure for the assembly test and the simplified test can be established on an individual basis and used for comparative testing and for assessing alternatives during product development. But it is very important that the manner of failure has been established using a sufficiently representative system test with either static, pulsating or dynamic loading applications.

FASTENER STRENGTH TESTS

Centric loading application (Method NT BUILD 306) (Appendix A)

NBI has developed a test method using the application of cumulative and pulsating loads on individual fasteners, which was accepted as a Nordtest Method in 1986. Detailed instructions are given for installing fasteners to be tested in bases of concrete, aerated concrete and metal sheet decks. The testing procedure is as follows.

The pullout strength for cumulative load must be tested first. The fastener and the base material in which it is mounted are secured in the testing machine in such a manner that any bending effects are as far as possible avoided. The machine is to be operated at a speed of 5 mm/min.

Testing with pulsating load must be carried out at load intervals that increase in steps which are 1/5 of the average capacity for static loading, rounded off to the nearest whole 100 N. The minimum increment is 100 N, the maximum 500 N. The load is increased by intervals within the defined load region until failure occurs.

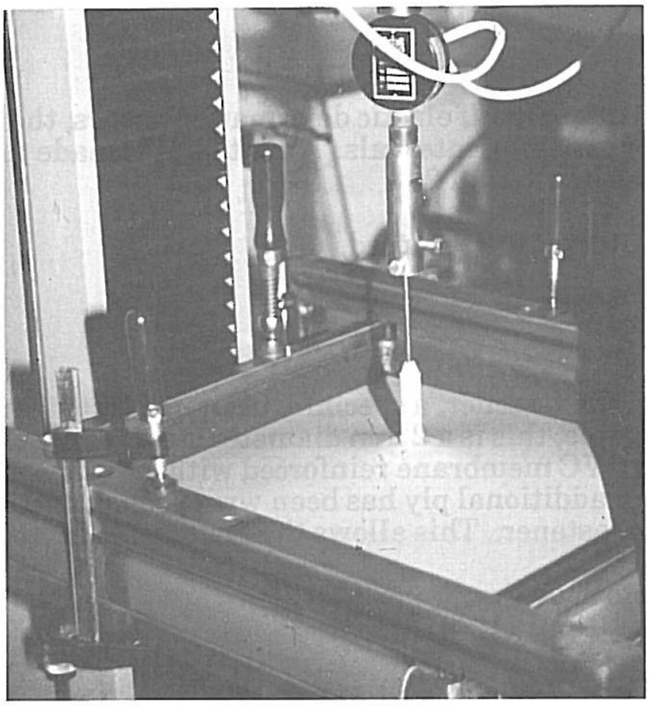


Photo 6
Simplified membrane strength test; pull through.

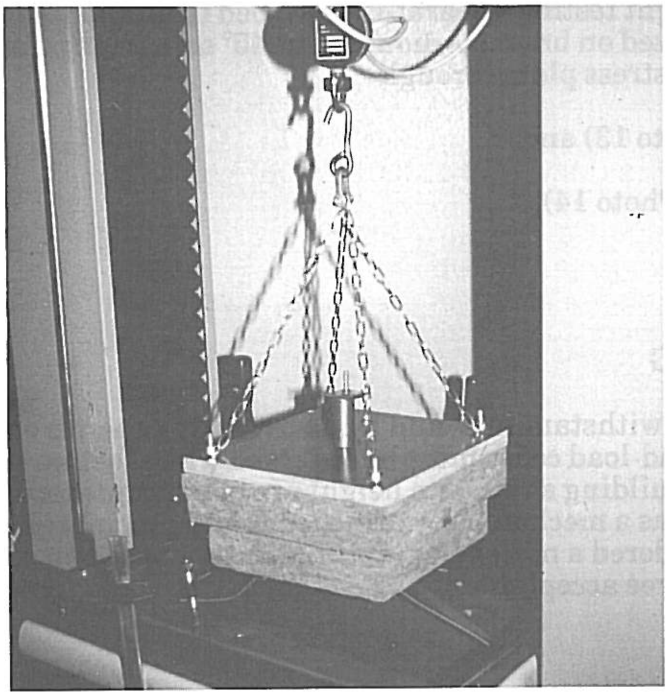


Photo 7
Simplified membrane strength test; flap strength

The deformation speed is 50 mm/min. If elastic deformation occurs, the speed is increased at interval 3 and succeeding intervals. An attempt is made to maintain the same total testing time as in interval 2.

Deformations at each load interval are recorded.

Eccentric load application

To transmit eccentric load to the fastener, a specially designed test strap has been developed (Photo 8). In principle, this is a 2 mm diameter steel wire welded between two plies of 1.2 mm PVC membrane reinforced with PES fabric. At the point of contact in the loop an additional ply has been wrapped around the wire to avoid a cutting action on the fastener. This allows the fastener to be tested by

- cumulative loading (Photo 9) or
- dynamic loading (Photos 10 and 11).

As stated in method NBI 164/91 (Appendix E), two ways of applying the load have been defined:

a) fixed drop heights
b) intervals of increasing drop heights.

The impact strength of plastic fasteners has also been studied to some extent.

The free-falling drop-weight testing apparatus described in method NT BUILD 335 (Photo 12) has been used on brackets mounted at 45° on a triangular wooden support for impact on the stress plate through

- bending upwards (Photo 13) and
- bending downwards (Photo 14).

DESIGN OF FASTENING

The required strength for withstanding wind load obviously depends on the degree of exposure. National wind-load codes must be observed when factors such as geography, topography, building shape and height are being considered. But for a secondary structure such as a mechanically attached roofing membrane where loss of human life is considered a minor risk, optimalization based on economic criteria is to a certain degree acceptable.

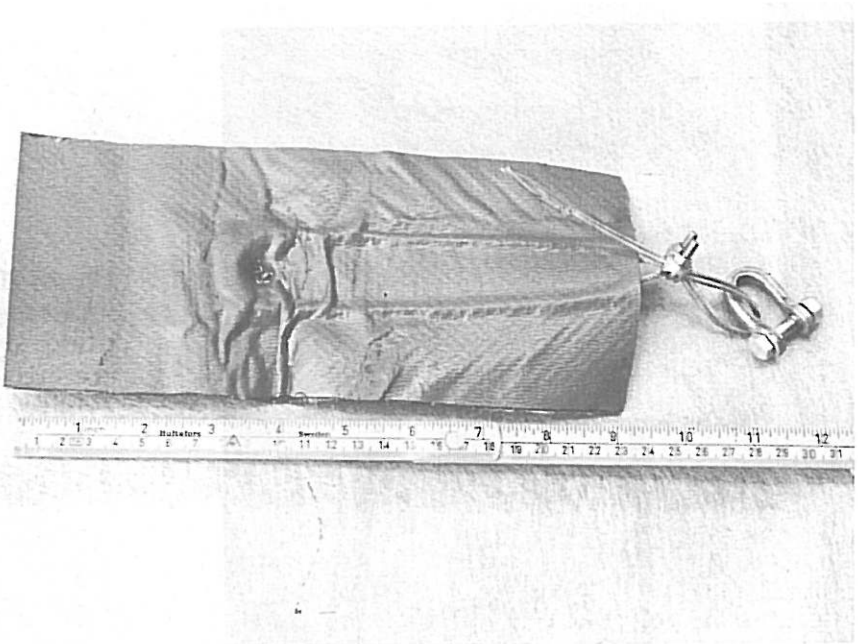


Photo 8
Test strap with wire reinforcement

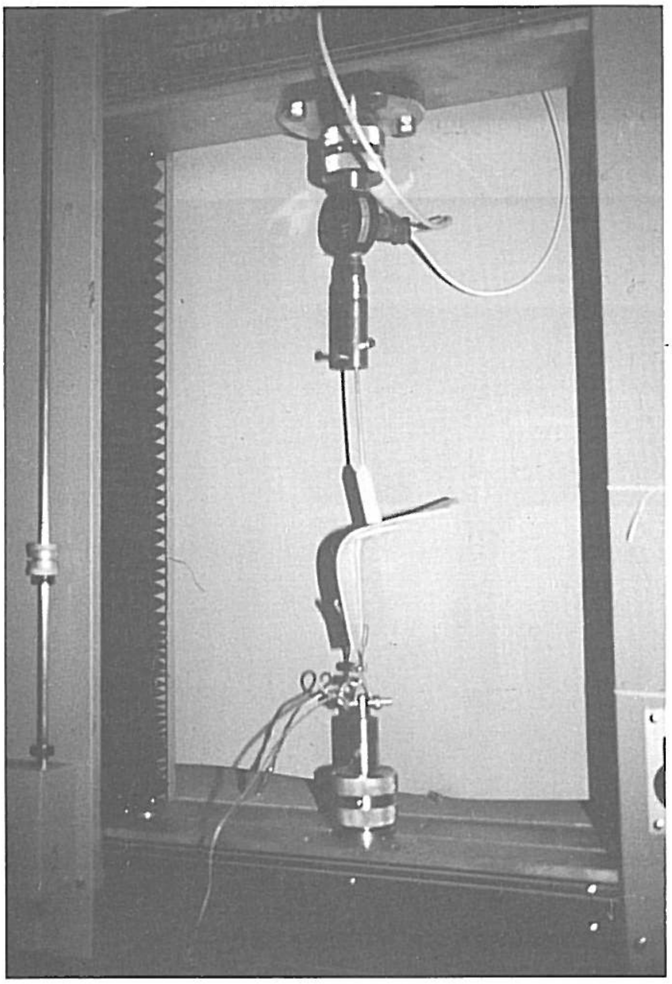


Photo 9
Fastener strength under eccentric axial loading

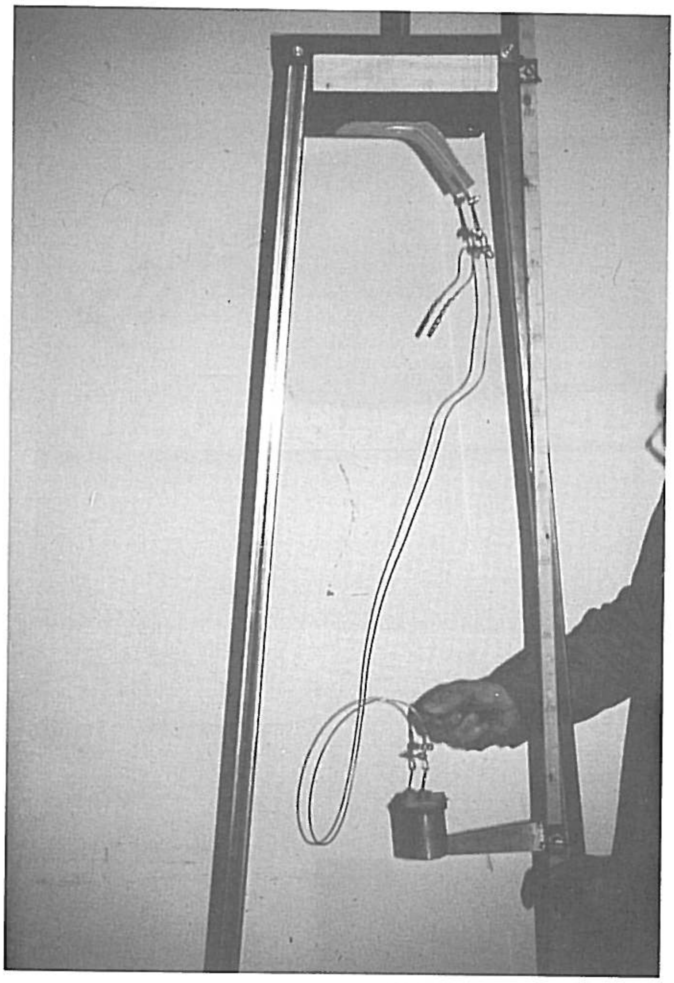


Photo 10
Fastener strength
under dynamic
eccentric loading

Photo 11
Detail of fixing arrangement against rubber pad

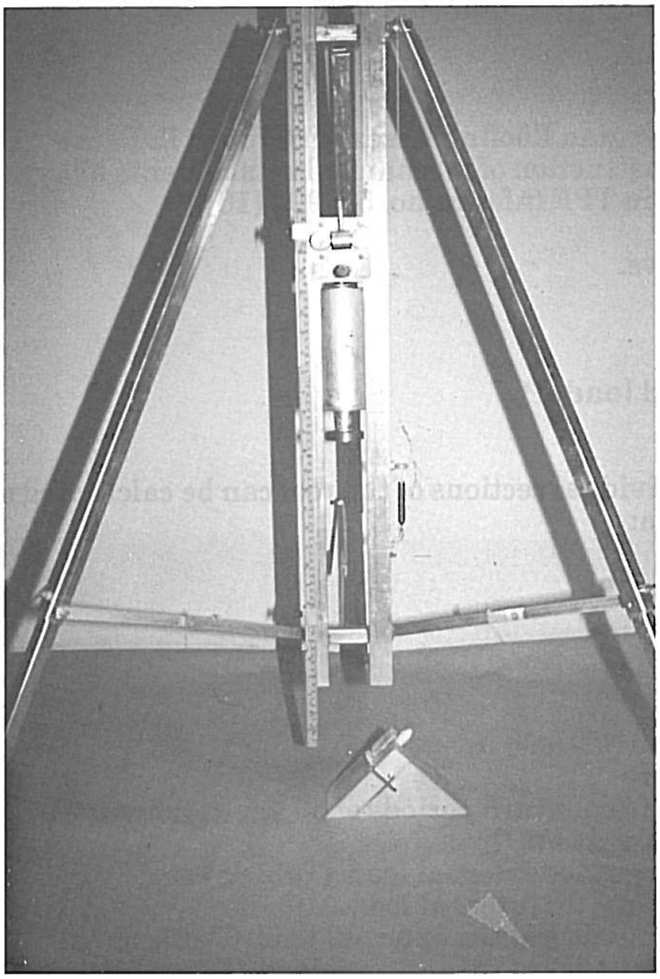
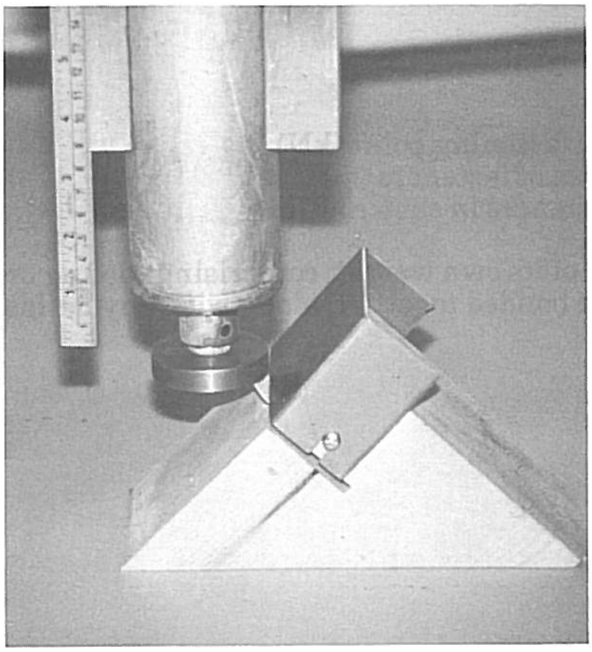


Photo 12
Drop-weight testing apparatus



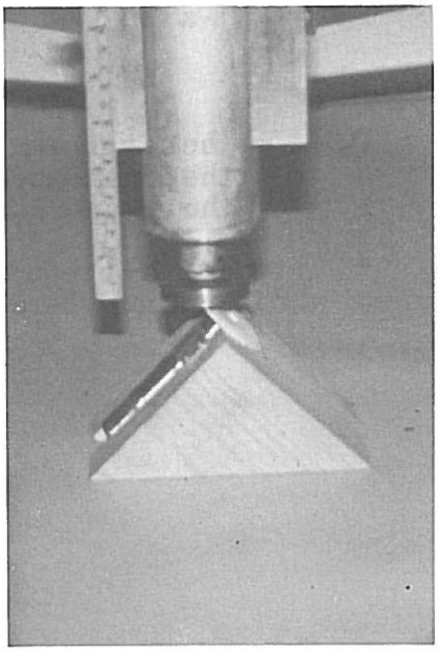


Photo 13
Bending upwards

Photo 14
Bending downwards

In cooperation with the Norwegian Roofing Research Group (TPF) the recommended design and construction of mechanical attachments has recently been updated and published in TPF Informs no. 5. 1990 [10].

The main points are as follows.

Calculation of design wind load, P_d

The design wind load for individual sections of the roof can be calculated on the basis of the following formula:

$$P_d = 1.6 \cdot 0.9 \cdot q\,(f_3 \cdot \mu_u + f_4 \cdot \mu_i)$$

where

P_d = the design wind load (kN/m2)
1.6 = the wind-load factor
0.9 = the lifetime factor (from return periods of 50 yrs to 20 yrs)
q = the dynamic pressure (kN/m2)
μ_u = the pressure coefficient for external load (Table 5)
μ_i = the pressure coefficient for internal load
f_3 = the factor for the efficiency of the external load (Table 6)
f_4 = the factor for the efficiency of the internal load (Table 7).

The design wind load per fastening point is calculated in the following manner:

$$P_d = p_d{}^* \cdot a \cdot b$$

where

P_d = the design wind load per fastening point (kN)
a = the distance between rows of fasteners (m)
b = the distance between fasteners in each row (m)

* The load can be reduced by 2/3 of its own weight, comprising roofing or roofing and insulation where these are bonded together, along with any ballast.

Table 5
Pressure coefficients (μ_u) for an external load on flat roofs, $\beta \leqq 6°$

Type of roof	Pressure coefficients μ_u		
	Corner area	Edge area	Centre area
Roofs with parapet	2.5	2.0	1.0
Pitch roofs	3.0	2.0	1.0
Monopitch roofs	High 4.0 Low 3.0	2.0	1.0

Table 6
Factors affecting the efficiency of an external load, f_3

Factor, f_3	Substructure
0.8	Impervious substructure and insulation between substructure and roofing membrane $\leq$ 100 mm
1.0	Open substructure or insulation between substructure and roofing membrane $>$ 100 mm

Table 7
Factors affecting the efficiency of an internal load, f_4

Factor, f_4	Substructure
0.0	Impervious substructure
1.0	Open substructure

Design capacity

The design capacity of the fastening assemblies must include fastening to both the substructure and the roofing (the insulation, if the roofing is bonded to the mechanically fastened insulation).

Suppliers give the design capacity of their products. These must comply with documented tests using equivalent types of substructure and roofing. The design capacity is given in, for example, the NBI Agrement.

Design capacity based on test methods

For tests in the field or laboratory, the design capacity can be calculated in the following ways.

Fastening to the substructure:

a. On the basis of tests using a cumulative load (this test is regarded as not particularly representative):

   In the laboratory:

   - plugs and screws $X_d = 0.5 \cdot 0.9\,(X_m - k \cdot s)$
   - nails and staples $X_d = 0.5 \cdot X_m$

   For pullout tests on the building itself:

   - plugs and screws $X_d = 0.75 \cdot 0.9\,(X_m - k \cdot s)$
   - nails and staples $X_d = 0.75 \cdot X_m$

   where

   X_d = the design capacity
   X_m = the mean value of the capacity during tests
   k = the factor for the number of tests
   s = the standard deviation

b. On the basis of tests using a pulsating load in accordance with method NBI 129/83 (NT BUILD 306):

   - plugs and screws $X_d = 0.9\,(X_m - k \cdot s)$
   - nails and staples $X_d = 0.7 \cdot X_m$

Fastening to the roofing membrane and insulation:

a. Cumulative load $X_d = 0.5 \cdot X_m$

b. Pulsating load in accordance with method NBI 92/85 (NT BUILD 307) (Appendix B) "Taktekningers styrke mot vindlast" ("The capacity of roofing membranes to withstand wind load"):

$$X_d = 0.7 \cdot X_m$$

Number of fasteners

To calculate the number of fasteners required, the design wind load (minus its own load) is divided by the design capacity.

Table 8 gives the requirements for minimum fastening of loosely laid roofing and insulation with plugs and self-drilling screws.

The minimum number of fasteners must also be considered in relation to the construction. Critical factors may be:

- movement of the insulation; in the case of loosely laid roofing membrane and insulation, there must be sufficient fasteners per insulating panel to prevent the panels becoming displaced beneath the roofing membrane
- movement in the roofing membrane. Fluttering can cause fatigue of the fastening or produce noises.

Table 8
Requirements for minimum fastening of loosely applied roofing membrane spot fixed with screws or plugs

	Roof exposed to moderate wind Curve A at $v < 40$ m/s Curves C and D	Roof exposed to strong wind Curve A at $v \geq 40$ m/s Curve B
Min. number of fixing pts.		
- per insulation panel	1	1
- per m^2	1	2
Max. distance between rows of fixing pts.		
- corner and edge areas	1.0 m	0.6 m
- centre area	no req.	1.0 m
Max. distance between fixing pts. in one row		
- corner and edge areas	1.0 m	0.6 m
- centre area	no req.	no. req.
Min. distance between fixing pts.	0.2 m	0.2 m

SUMMARY AND RECOMMENDATIONS

Design concept

When NBI first introduced its design concept for roofing fasteners in 1980, it was based on the quasi-static approach presented in the pending Norwegian Standard for Design Loads, NS 3479, published in 1981.

The wind load was related to the gust wind speed with the use of mean pressure coefficients. The capacity of the structure was determined using an assembly test with pulsating air pressure (NT BUILD 307). The strength of individual fasteners was tested under axially centric pulsating loading (NT BUILD 306).

The roofing system was looked upon as a more or less static structure and the number of fasteners was worked out as an ordinary design calculation. This proved to be sufficiently accurate because at that time the systems used were mainly two-ply bituminous membranes or membranes bonded to insulation panels. But with the rapid increase in the use of mechanically attached, polymeric sheet roofing membranes it became evident that the dynamic aspect of testing should be given more attention.

The first documented cases where backout was confirmed are shown in Photos 15-17. The relatively few cases of backout recorded are probably explained in Photos 18-20, where the fasteners have been installed in a double-layered section of membrane. The usual way of fixing at the membrane edge or in the flaps was not strong enough to cause rotation of the screw. Failure by tearing around the stem would appear first, and we have seen this to be a common cause of roofing blowing off.

Laboratory testing

The methods for applying dynamic loading presented in this report offer new opportunities for a more realistic estimate of the actual performance of loosely applied, mechanically fixed membrane systems.

Tests on individual fasteners and simplified membrane tests have been introduced to reduce the cost of testing.

It is important that the way a particular system has failed is established using an appropriate full-scale test. Applying static loading may be sufficiently accurate for a bonded system. If the fastener is located in a fully bonded overlap joint of an asphalt felt and the mode of failure is pull through of the stress plate in the membrane, a linear correlation exists between the assembly test and the simple pull-through test.

Guide for the future

The quasi-static principle of loading has been retained in the newly revised design recommendations presented in TPF Informs No. 5, 1990.

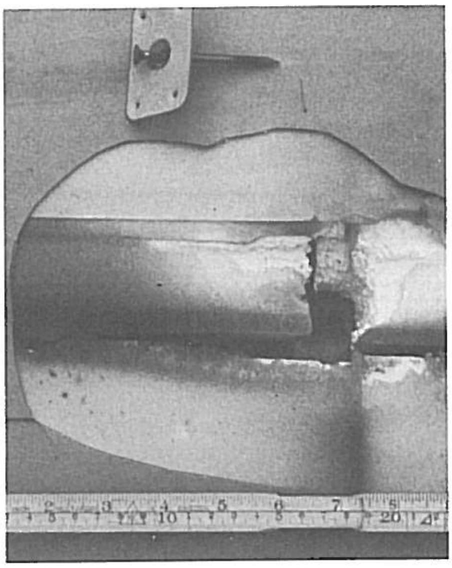


Photo 15
Roof I;
screw backout

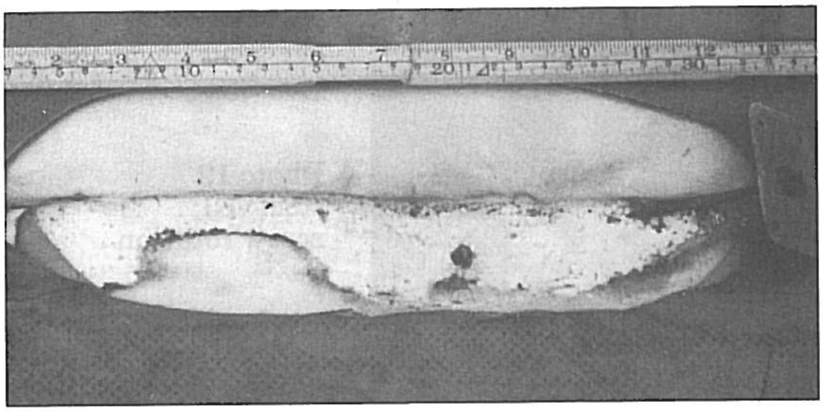


Photo 16
Roof I;
loss of pre-tensioning

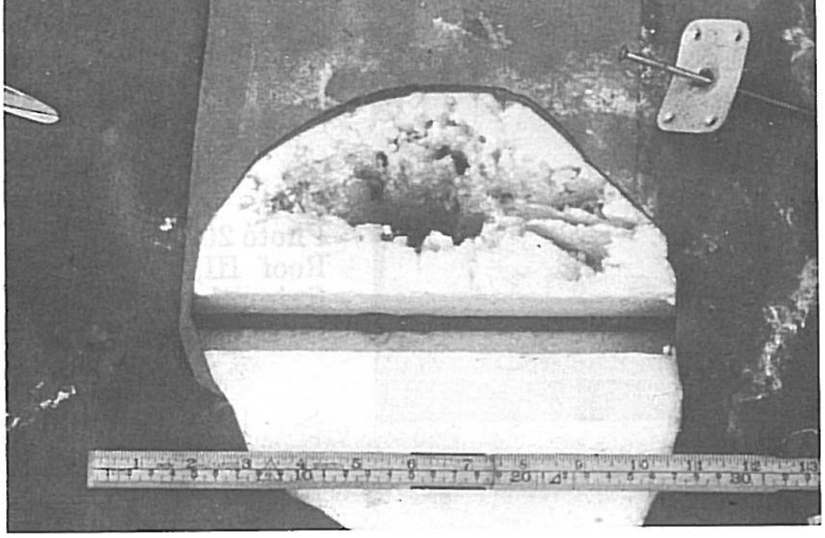


Photo 17
Roof II;
screw backout

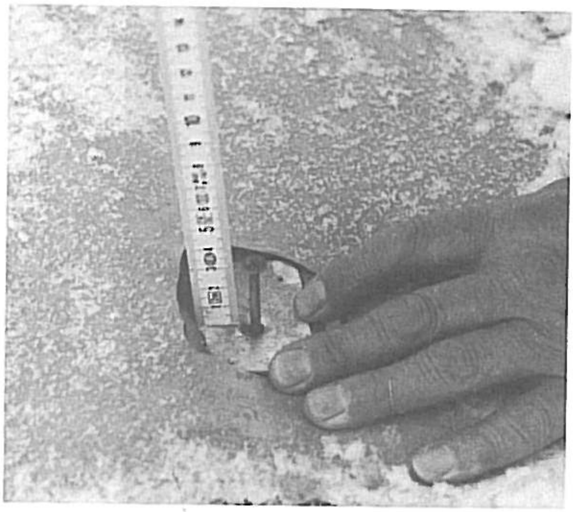


Photo 18
Roof III;
screw backout

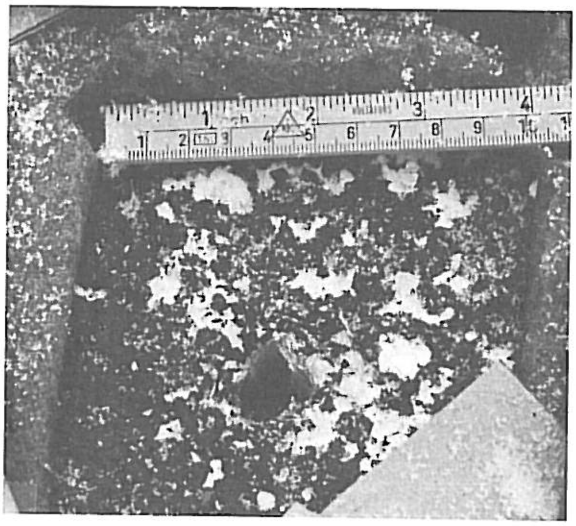


Photo 19
Roof III;
screw rotation

Photo 20
Roof III;
fixing through two
layers of membrane

The limit-state design is the basic concept used. This is the fundamental principle upon which the new Eurocodes for design of structures will be based. However, a mechanically attached membrane construction is considered to be a secondary structure where the risk for loss of human life if damage occurs is thought to be relatively slight.

The idea of transforming the capacities into a design for an equivalent static structure have proved to be practical and sufficiently accurate. There is, however, a need to develop tools for design such as:

- a classification of roofing systems into static, dynamic or aeroelastic structures and the identification of ways of reverting to better stability
- determining ways in which systems typically fail
- establishing correlation factors between assembly tests and simplified membrane strength tests
- developing criteria for the minimum strength of fasteners under dynamic eccentric loading.

The almost aeroelastic behaviour of mechanically attached polymeric sheet membrane when something like resonant flutter occurs, lies on the borderline of existing knowledge.

In the new test facilities, where dynamic air suction can be applied at temperatures from +40 °C to –10 °C, NBI has been able for the first time to simulate under laboratory conditions several types of failure mechanisms found in practice.

The challenge for the near future is to analyse data from field measurements of membrane movements and loads on fasteners. This information is stored as analog recordings on magnetic tapes.

Better information and understanding of field performance is needed before the dynamic test concept can be fully adopted in designs for roofing membrane fasteners.

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ROOF COVERINGS:
STRENGTH OF MECHANICAL FASTENERS

1. SCOPE

This method provides a way of finding the pullout strength of mechanical fasteners for roof coverings exposed to axial symmetric loading. Both static and pulsating loads are used. (In the case of unsymmetrical loadings, the strength must be evaluated separately).

For a system test of strength of resistance against wind load, see NORDTEST method NT BUILD 307.

2. FIELD OF APPLICATION

This method can be used for all types of fasteners used for mechanical attachment of roof coverings, such as self-threading screwes, and various types of expansion plugs. The base material used may be concrete, aerated concrete, or steel deck.

3. REFERENCES

NBI Building Data Sheet, A544.206. Mechanically fixed roof coverings.

published by

NORDTEST
Postbox 22
SF-00341 HELSINGFORS
Finland

key words

roof coverings
mechanical fasteners
test method

classification

UDC 69.024.15

ISSN 0283-7153

4. DEFINITIONS

The pullout strength under static load is the greatest centric capacity obtained. The pullout strength under pulsating load is the greatest capacity obtained, or the capacity when permanent deformation is >6 mm.

5. SAMPLING

As a rule, samples are tested as delivered. Ten samples are to be tested for each type of load, i.e., 10 for static load and 10 for pulsating load.

6. TEST METHOD

6.1 Principle

First the pullout strength under static load is found under uniformly increased loading then the pullout strength under pulsating load is found under incrementally increased pulsating load.

6.2 Apparatus

- Test machine which can be operated with both static and pulsating tensile forces
- Load cell to measure the force
- Deformation gauge
- Holding device
- Device for applying force to the fastener. The top disc shall bear on a steel plate having a 10 mm slot and a 30 mm diameter hole.

6.3 Preparation of test samples

The fasteners shall not be prepared in any way, but it is important that they are mounted according to the manufacturers' instructions, and in the same manner as is used when attaching roof coverings in practice. Mounting shall be done through insulation, if the fastener is intended for such use.

Base Material

Concrete:

Unless otherwise specified, 50 mm concrete slabs of qualility C55 and at least three weeks old shall be used (5 samples are to be attached to slabs 300 mm x 600 mm). The drilled hole ought to be at least 10 mm deeper than necessary for the fastening of the plugs, due to the cuttings which fall into the hole. Therefore the hole will usually penetrate the sample.

Steel decks:

The fastener is mounted in the top horizontal section of the profile, not in the grooves.

Aerated concrete:

For aerated concrete, the fasteners shall be mounted in both wet and dry material (10 in each, both for pulsating and static loadings). Wet aerated concrete is obtained by keeping the material submerged in water for 72 hours, and drying it in open air at +23°C for 24 hours. In addition, it should be possible to mount the fasteners in completely wet aerated concrete. The depth of fastening in aerated concrete should be at last 50 mm.

6.4 Procedure

The static pullout strength shall be tested first. The fastener and the base material in which it is mounted are secured in the test machine in such a manner that any effects of bending are as far as possible avoided. The machine shall be operated at a speed of 5 mm/min.

Testing with pulsating load shall be carried out at load intervals with increments increasing by 1/5 of the average capacity for static load, though rounded off to the nearest whole 100N. The minimum increment is 100N, the maximum increment 500N. In each interval, 200 load cycles (loading and unloading) shall be applied. The load is increased by intervals in the defined load region until breakage occurs. Deformation speed is 50 mm/min.

For tests with elastic deformation, the speed is increased at interval 3 and the following intervals. Attempt is made to maintain the same total testing time as in interval 2. Deformations at each load interval are recorded.

6.4 Expression of results

The pullout strength is found for each fastener (see pt. 4.) The mean (X_m) and standard deviations for each series is calculated.

6.5 Test report

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organization or the person who ordered the test
d) Purpose of the test
e) Method of sampling and other circumstances (date and person responsible for the sampling)
f) Name and address of manufacturer or supplier of the tested object
g) Name or other identification marks of the tested object
h) Description of the tested object
i) Date of supply of the tested object
j) Date of the test
k) Test method
l) Conditioning of the test specimens, environmental data during the test (temperature, pressure, RH, etc)
m) Identification of the test equipment and instruments used
n) Any deviations from the test method
o) Test results (use SI units)
p) Inaccuracy or uncertainty of the test result
q) Date and signature

nordtest method

NT BUILD 307

Approved 1986-11

ROOF COVERINGS:
WIND LOAD RESISTANCE

1. SCOPE

The test method is designed to assess the wind load resistance of roof assemblies.

For the strength of mechanical fasteners, see NORDTEST method NT BUILD 306.

2. FIELD OF APPLICATION

The method is used for:

- assessing the resistance to blow-offs of sheet applied membranes either bonded to the base material or mechanically fixed to it
- assessing the resistance to blow-offs of insulation materials either bonded to the base material or mechanically fixed to it
- assessing the strength and stiffness of plate materials used for roofing, either with insulation applied to the roofing material or without any such insulation, including fastening systems used for attaching the material to the base as well as the strength of the sheet itself.

published by

NORDTEST
Postbox 22
SF-00341 HELSINGFORS
Finland

key words

roof coverings
wind load resistance
test method

classification

UDC 69.024.15

ISSN 0283-7153

3. REFERENCES

NBI Test Method 92/85 Roof Coverings, Wind load resistance,
NBI Building Data Sheet, A.544.206 Mechanically fixed roof coverings.

4. DEFINITIONS

P = The static pressure applied at each load level where deflection is measured.

A failure is when the fixing is damaged or leakage in the membrane is recorded. Permanent deformation in the fixing system or membrane which reduces the water-proofing function over time is also recorded as failure.

5. SAMPLING

The test roof assembly used should be built up in the same manner as in practice. Usually more than one test of each type of construction is made.

If the geometry of the fixing system varies, the extremes referring to low and high numbers of fixing points must be tested.

6. TEST METHOD

6.1 Principle

The roof assembly is mounted in a sealed box. A pressure difference is applied across the assembly, and measurement is made of how much the construction can tolerate without failure.

6.2 Apparatus

The apparatus for the air pressure test on roof constructions is shown in Fig. 1. In principle it may consist of one or two boxes, one upper or one lower, or both with the roof assembly at one side or between. The box(es) is airtight so that the pressure can be regulated in accordance with the appropriate pressure program. When testing at other than ambient temperature, provision must be made to control the test conditions.

6.3 Preparation of test samples

Normal variations regarding workmanship should be taken into account for when preparing the test assembly.

Roofing systems where the wind load strength is affected by bad weather conditions during installation, must be prepared at simulated working condition (e.g. frost, heat, rain etc).

Large variations must be tested separately.

Preferred test temperatures are +23 °C, ±0 °C and -10 °C.

6.4 Procedure

Alternative A. Static pressure test.

The apparatus usually consists of one upper box.

The load is applied as negative pressure with increasing intensity as shown in Table 1.

Table 1. Loading conditions static pressure test

Load interval	Static pressure Pa	Load interval	Static pressure Pa
1	500	7	3500
2	1000	8	4000
3	1500	9	5000
4	2000	10	6000
5	2500	11	7000
6	3000		

For each load interval the pressure is gradually increased to its appropriate level, then held constant for 5 min to allow for measurements of deflection and then decreased to zero.

At the end of each pressure interval, the apparatus is turned off and the roof assembly inspected for signs of permanent deformation or damage.

Alternative B. Pulsating pressure test.

The apparatus is most conveniently operated with two boxes, - a LOWER box with static positive pressure and an UPPER box with pulsating negative pressure.

The load is applied as specified in Fig. 2 and Table 2 with increasing intensity as shown in sequence of operation in Fig. 3.

The different components of pressure are operated as follows:

1) First a static negative pressure is applied to the UPPER box corresponding to 0,6 of the total static pressure P on the assembly for the desired load interval. The pressure is maintained for 5 minutes.

2) Immediately after applying the suction in stage 1, a positive pressure of 0,4 P is applied to the LOWER box. Deformation is then measured under the static pressure P.

3) In this phase, the negative pressure on the upper side is pulsating. It is run continually for 20 minutes with an amplitude of ± 0,4 P, so that the pressure varies between P and 0,23 P. The frequency is about 4 pulsations per minute.

4) At the end of each pressure interval, the apparatus is turned off and the sample inspected for signs of permanent deformation or damage.

6.5 Expression of results

Alternative A.

The capacity at failure for the static pressure test is found from the maximum pressure recorded when failure occurs.

Alternative B.

The capacity at failure for the pulsating pressure test is the total pressure at each load level given in Table 2. If failure occurs at the stage with static pressure or before the first peak of pulsating pressure is reached, then the previous pulsating pressure level is quoted.

Average capacity at failure with A and B can be given for each fixing point, if the system capacity is linear with the number of fixing points.

6.6 Test report

The test report shall include the following information, if relevant:

a) Name and address of the testing laboratory
b) Identification number of the test report
c) Name and address of the organization or the person who ordered the test
d) Purpose of the test
e) Method of sampling and other circumstances (date and person responsible for the sampling)
f) Name and address of manufacturer or supplier of the tested object
g) Name or other identification marks of the tested object
h) Description of the tested object
i) Date of supply of the tested object
j) Date of the test
k) Test method
l) Conditioning of the test specimens, environmental data during the test (temperature, pressure, RH, etc)
m) Identification of the test equipment and instruments used
n) Any deviations from the test method
o) Test results (use SI units)
p) Inaccuracy or uncertainty of the test result
q) Date and signature

Table 2

Loading condition pulsating pressure test

Load interval	Static load			Pulsating negat. pressure			Total load
	Pressure UPPER LOWER box	Static load	Time	Highest limit	Lowest limit	Time	
	Pa	Pa	min	Pa	Pa	min	Pa
1	-300 200	500	5	500	100	20	700
2	-600 600	1000	5	1000	200	20	1400
3	-900 600	1500	5	1500	300	20	2100
4	-1200 800	2000	5	2000	400	20	2800
5	-1500 1000	2500	5	2500	500	20	3500
6	-1800 1200	3000	5	3000	600	20	4200
7	-2100 1400	3500	5	3500	800	20	4900
8	-2500 1500	4000	5	4000	1000	20	5500
9	-3100 1900	5000	5	5000	1200	20	6900
10	-3700 2300	6000	5	6000	1400	20	8300
11	-4300 2700	7000	5	7000	1600	20	9700

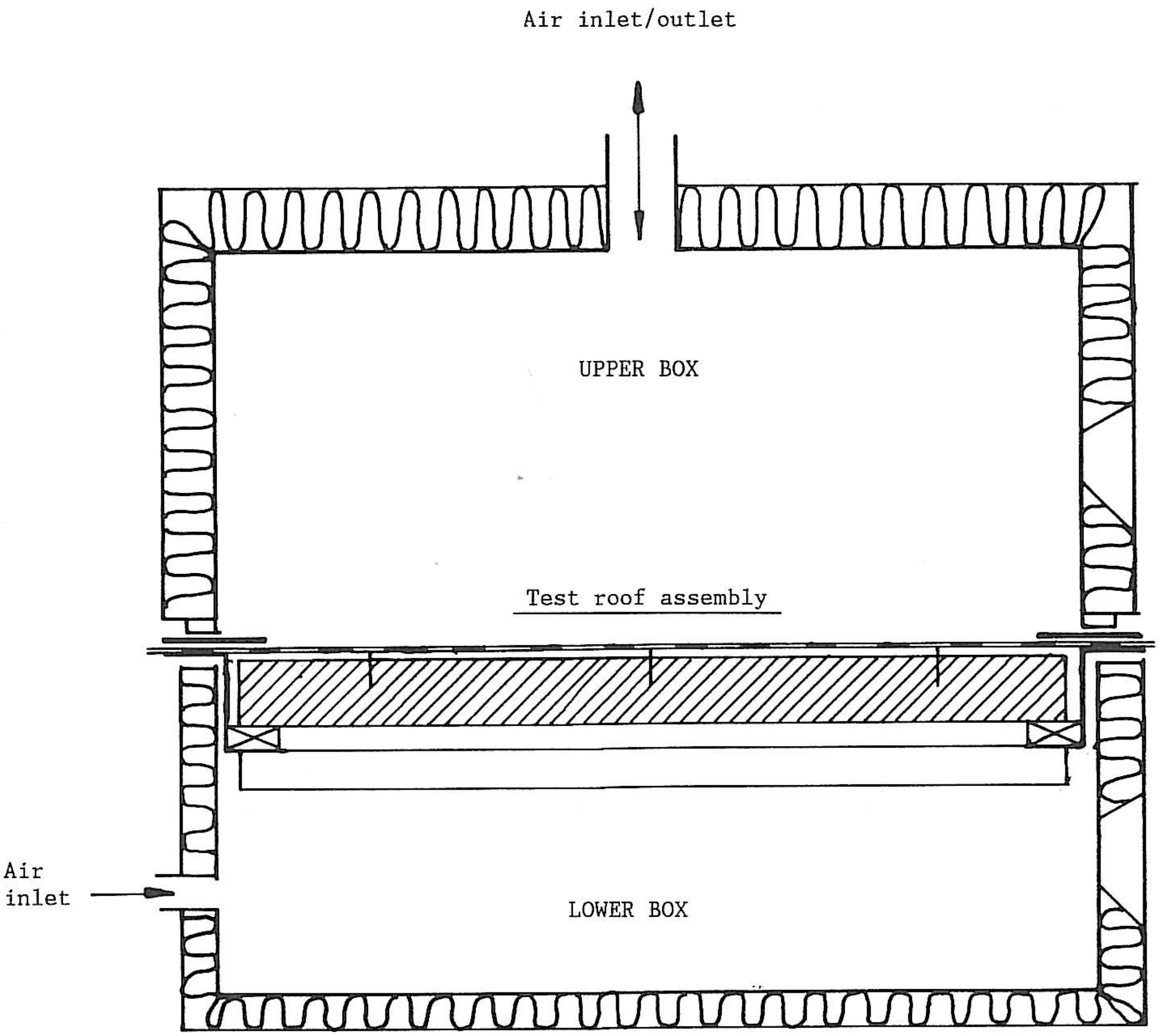


Fig. 1. Roof testing apparatus.

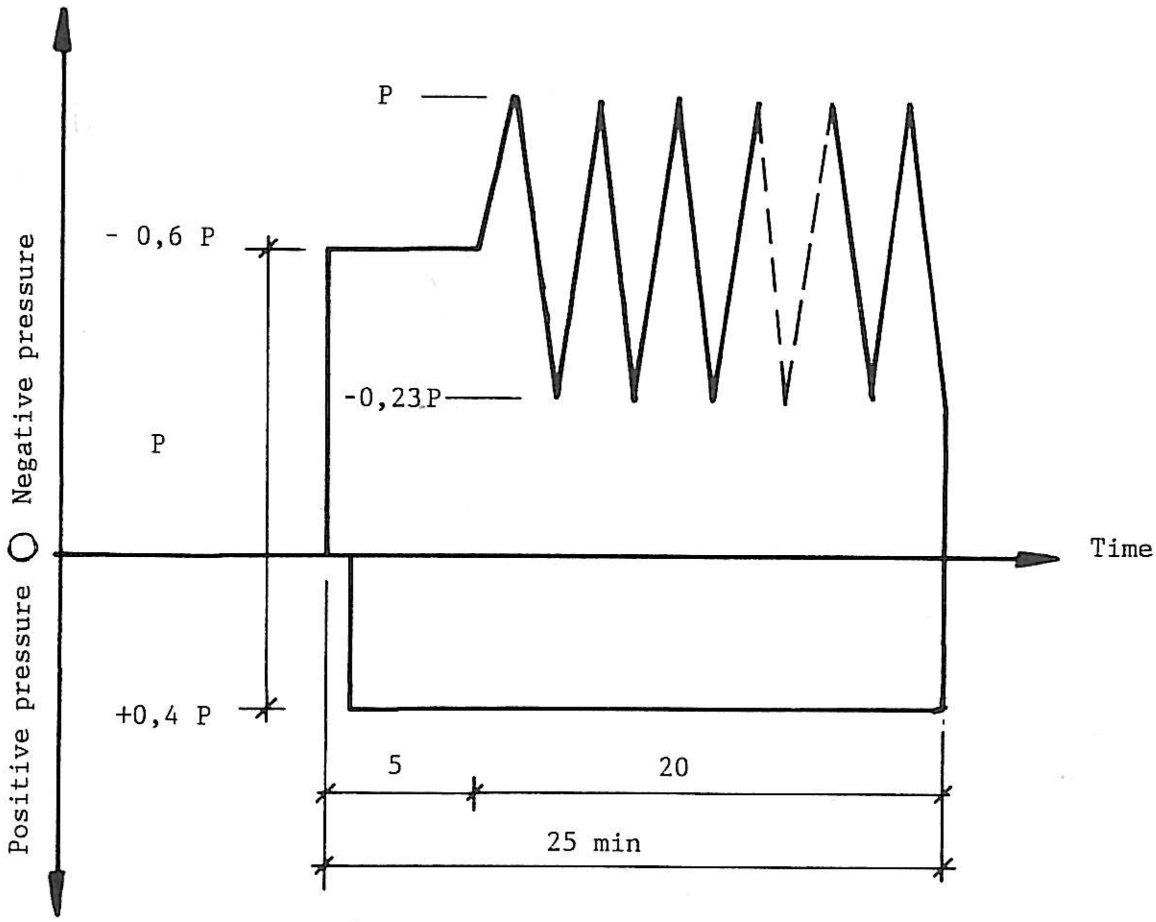


Fig. 2. Detail of pressure pattern.

Load interval	1	2	3	4	5	6	7	8	9	10	11
Total load (Pa)	700	1400	2100	2800	3500	4200	4900	5500	6900	8300	9700
Static load (Pa)	500	1000	1500	2000	2500	3000	3500	4000	5000	6000	7000

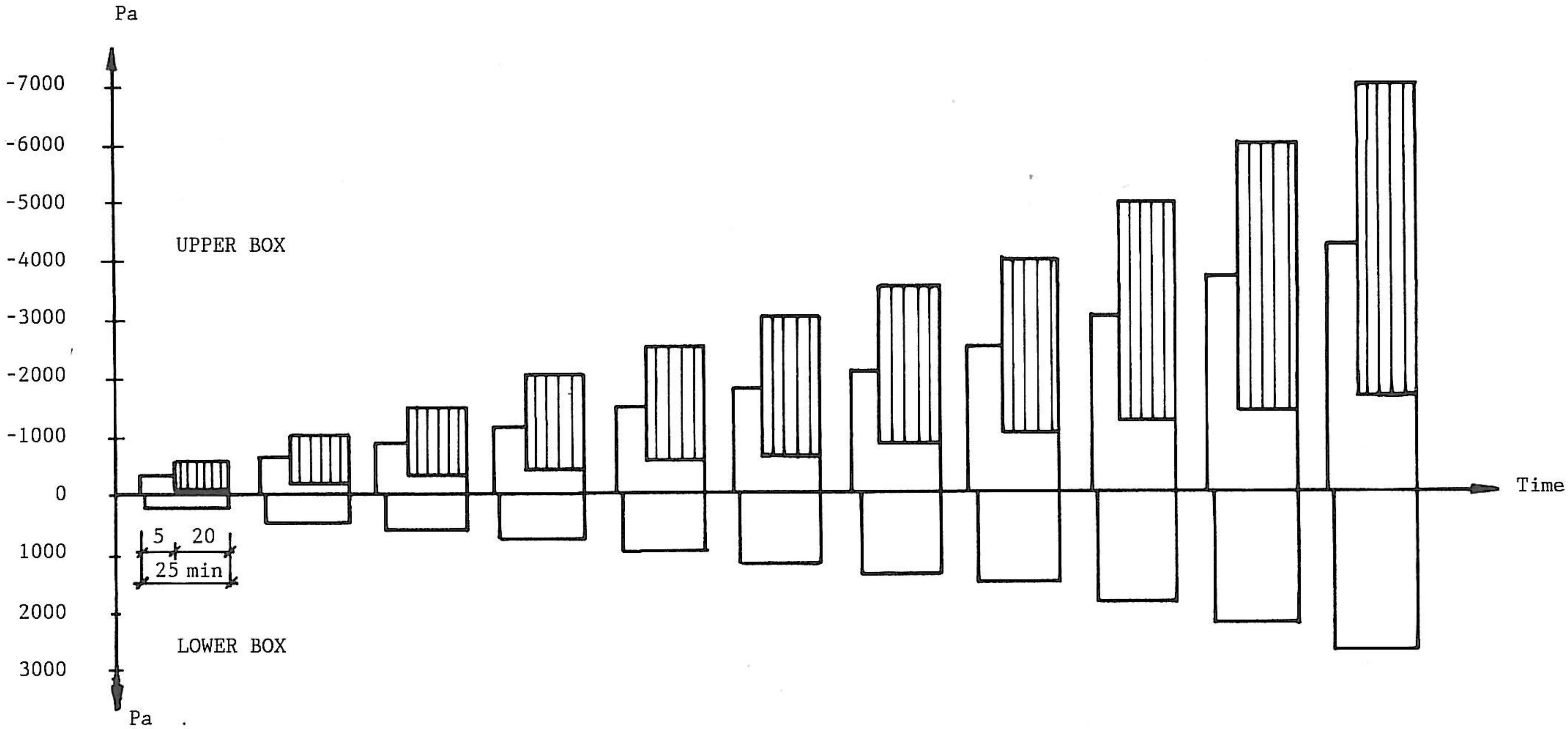


Fig. 3. Sequence of operation

ROOF COVERINGS: Dynamic wind-load resistance

1. SCOPE

This test method is designed to assess how well mechanically attached roofing membranes withstand the effects of dynamic wind load.

For testing wind-load resistance to static or pulsating air pressure, see NORDTEST method NT BUILD 307.

2. FIELD OF APPILICATION

The method is used to assess

- how well self-drilling or self-tapping screws used for fastening membranes to profiled metal sheets resist backout
- how well sheet-applied membranes fixed with mechanical fasteners resist being blown off
- the influence of the airtightness of the substructure on the transfer of reactions to the fastener
- the resistance of fastener fatigue at fixing points in the substructure

3. REFERENCES

PAULSEN, Einar M.: Roofing systems with mechanical attachments. Testing with dynamic loads.

4. DEFINITIONS

P = the static negative pressure applied as a uniform load on the membrane whilst dynamic loading is being applied

P_d = the dynamic negative pressure applied as gusts of suction to the storage tank; the suction intensity quoted is instantaneous pressure measured at the air intake slit above the roofing membrane.

A failure can occur in one or more of the following ways:

- backout of screws while they are being fixed to profiled metal sheets
- breakage in the fastener itself
- breakage at the point where the membrane is fixed, or impairment of the waterproofing function
- permanent deformation of the membrane or fixing system, which may reduce the waterproofing function over time
- pullout of the fastener from load-bearing substructure.

5. SAMPLING

The roof assembly used for testing should be built up in the same manner as under normal use. If the geometry of the fixing system varies, the constructions that have the lowest and highest numbers of fixing points must be tested.

6. TEST METHOD

6.1 *Principle*

The roof assembly is mounted in a sealed box. A pressure difference is applied across the assembly, and a measure of how much the construction can tolerate without failure is obtained.

6.2 *Apparatus*

The apparatus for determining dynamic wind-load resistance is shown in Fig. 1. It is basically the same apparatus as for standard wind-load testing, NT BUILD 307, but with the following additions:

- an 11 m^3 steel tank to store air at low pressure
- a 500 mm diam. release valve
- an air intake slit positioned between rows of fasteners and connected to the main air duct by flexible tubes
- a 200 mm wide section without insulation in the roof assembly beneath the air intake slit and between the rows of fasteners
- pressure equalization between load applications

When testing at other than ambient temperature, provision must be made to monitor the test conditions.

6.3 *Preparation of test samples*

Normal variations in workmanship should be allowed for when preparing the roof for testing.

Roofing systems whose wind-load strength is liable to be affected by bad weather conditions during installation must be assembled in a manner which simulates working conditions (e.g. frost, heat, rain, etc.).

Large variations must be tested separately.

Preferred test temperatures with an accuracy of ±5°C are +40 °C, +23 °C, ±0 °C and –10 °C.

6.4 *Procedure*

The dynamic load is applied as gusts of suction in a 30 mm wide slit positioned above the roofing membrane and between the rows of fasteners where the insulation has been removed.

The membrane under the air intake slit is lifted up first, with the result that a non-axial load is transmitted to the fasteners.

The dynamic gusts are applied in load intervals lasting 60 minutes and are increased in intensity as shown in Table 1.

Table 1. Loading conditions for the dynamic pressure test

Load interval	Dynamic pressure Pa	Load interval	Dyanmic pressure Pa
1	–200	7	–1400
2	–400	8	–1600
3	–600	9	–1800
4	–800	10	–2000
5	–1000	11	–2200
6	–1200	etc	

The suction intensity quoted is the instantaneous pressure measured at the air intake slit above the roofing membrane.

At the end of each load interval, the apparatus is turned off and the roof assembly is inspected for signs of failure.

The following loading programmes have so far been defined and used in the testing:

A: Dynamic loading in intervals of encreasing intensity (Fig. 2).
Suction is applied as gusts every 15 sec. for one hour per load interval. The intensity of the gust is increased in steps of 200 Pa from one load interval to the other.

B: Static loading as constant negative pressure to lift the membrane from the base and
Dynamic loading, the same as for A (Fig. 3)

C: Dynamic loading with fixed intensity (Fig. 4).
Gusts of suction applied continuously every 15 sec.

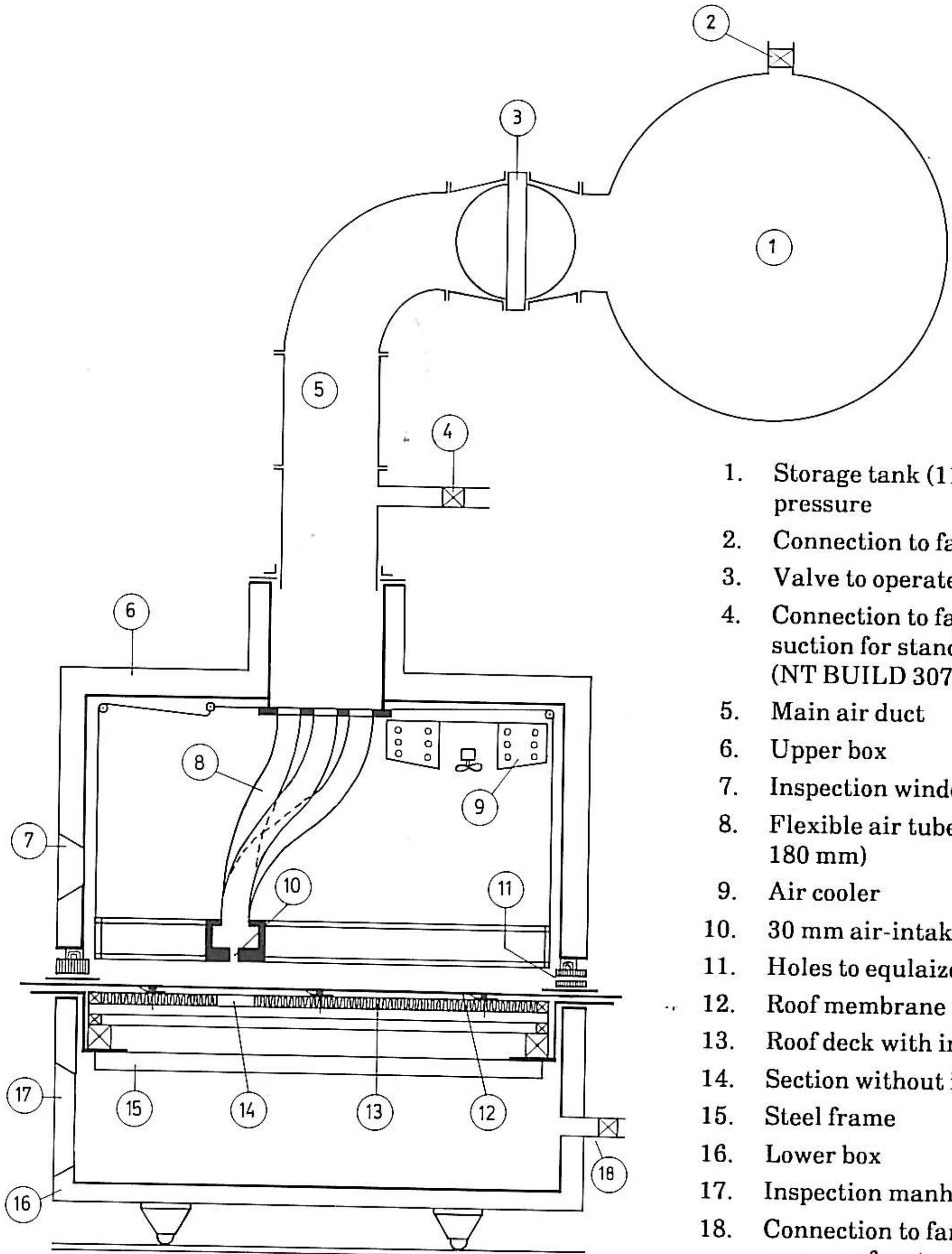
6.5 *Expression of results*

For loading programmes A and B, the load interval at which failure occur is recorded.

For loading programme C, the total testing time in hours to when failure occur is recorded.

6.6 *Test report*

Use NBI-G01, paragraph 6.7, and include the elements applicable to this test method.



1. Storage tank (11 m³) for air at low pressure
2. Connection to fan for air evacuation
3. Valve to operate dynamic suction
4. Connection to fan operating pulsating suction for standard wind-load testing (NT BUILD 307)
5. Main air duct
6. Upper box
7. Inspection window
8. Flexible air tubes (7, with diam. 180 mm)
9. Air cooler
10. 30 mm air-intake slit
11. Holes to equlaize pressure after gust
12. Roof membrane with fasteners
13. Roof deck with insulation
14. Section without insulation
15. Steel frame
16. Lower box
17. Inspection manhole
18. Connection to fan operating static pressure for standard wind-load testing (NT BUILD 307)

Fig. 1
Roof testing apparatus

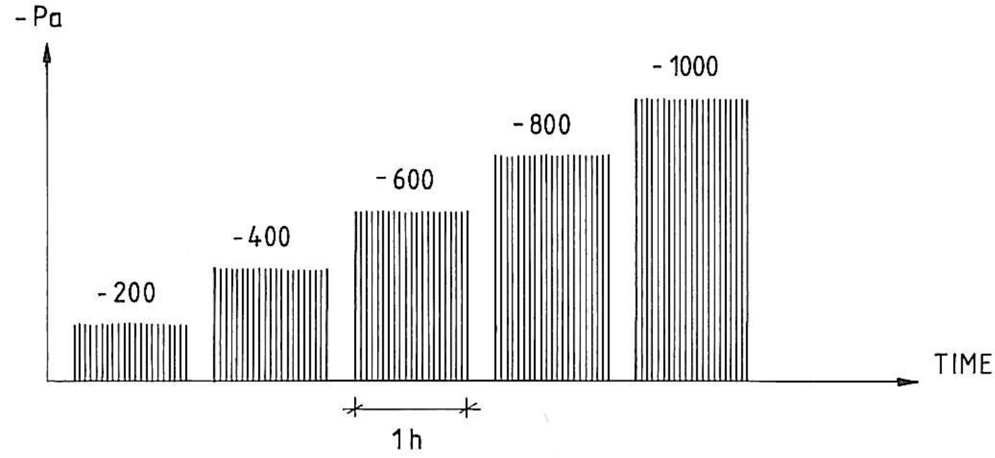


Fig. 2 Dynamic load
Intervals with increasing intensity

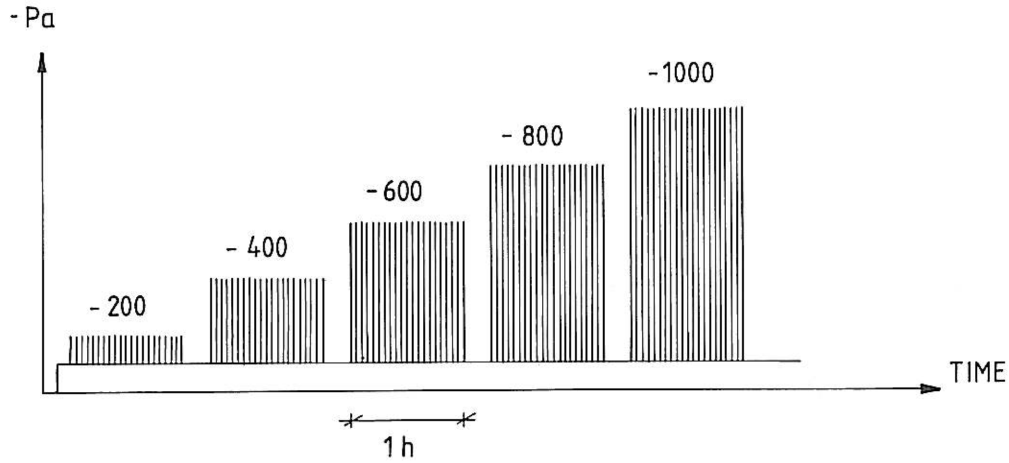


Fig. 3 Static + dynamic load
Intervals with increasing intensity

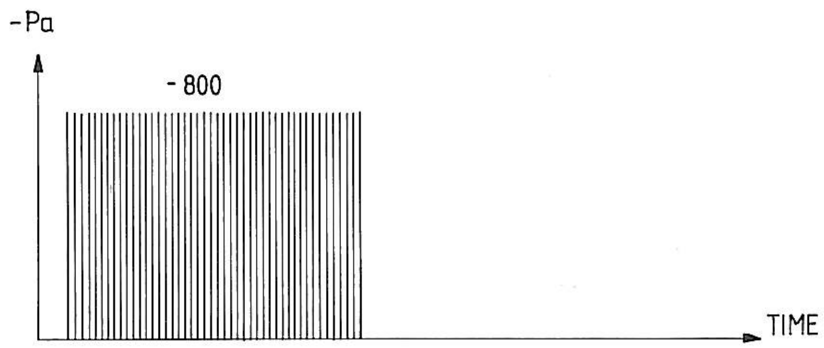


Fig. 4 Dynamic load
Fixed intensity

ROOF COVERINGS: Fastener pull-through strength in membrane

1. SCOPE

The test method is designed to assess the fixing strength in membrane of individual fasteners using cumulative loading.

For testing the fixing strength of fasteners in membrane using assembly tests, see methods:

- NT BUILD 307 Roof coverings: Wind-load resistance with static or pulsating air pressure.
- NBI 162/91 Roof coverings: Wind-load resistance with dynamic air pressure.

2. FIELD OF APPLICATION

This metod is used to assess the pull-through resistance in membrane of

- clout nails with heads up to 20 mm in diameter and where the membrane is fixed between metal rings having an internal diameter of 125 mm
- mechanical fasteners with stress plates >20 mm and where the membrane is fixed to a nail-studded metal frame measuring 400 mm by 400 mm

3. REFERENCES

4. DEFINITIONS

The pull-through strength under cumulative loading is the greatest capacity obtained at failure.
A failure can occur in one or more of the following ways:

- pull through of the fastener in the membrane
- tearing around stress plate or fastener stem during fixing in the underlying flap
- breakage of the fastener itself or permanent deformation of the stress plate in excess of 6 mm

5. SAMPLING

As a rule, samples are tested as delivered. Five samples must be tested for each variable.

6. TEST METHOD

6.1. *Principle*

The pull-through strength is determinded by subjecting the test specimen to a cumulative load until failure occurs.

6.2 *Apparatus*

- a tensile testing machine which can be operated at a uniform deformation speed
- a load cell to measure the force
- a deformation gauge
- devices for holding specimens
  - a) Ø 125 mm clamping ring for clout nails up to 20 mm in diameter. (Fig. 1).
  - b) a 400 mm x 400 mm nail-studded metal frame for fasteners with stress plates >20 mm. Fasteners in flaps are mounted on 50 mm insulation and pretensioned against a plywood load-application plate. The flap is cut on the inside of the metal frame. (Figs. 2 and 3).

6.3 *Preparation of test samples*

The fasteners must not be prepared in any way, but it is important that they are mounted in a defined manner.

For pull-through tests using clout nails and fasteners, the mounting should be in the centre of the test specimen.

To test the strength of fixing in the underlying flap, the fastener should be given normal pre-tension against the insulation which is 50 mm thick mineral wool with high compressive strength (Rockwool TP 200).

Testing is usually carried out in a room with controlled temperature and humidity, 296 K ± 2 K (23 ± 2 °C) and RH 50%.

6.4 *Procedure*

The fastener and the membrane test specimen in the proper fixing device are mounted in the test machine in such a manner that any effects of bending are as far as possible avoided.

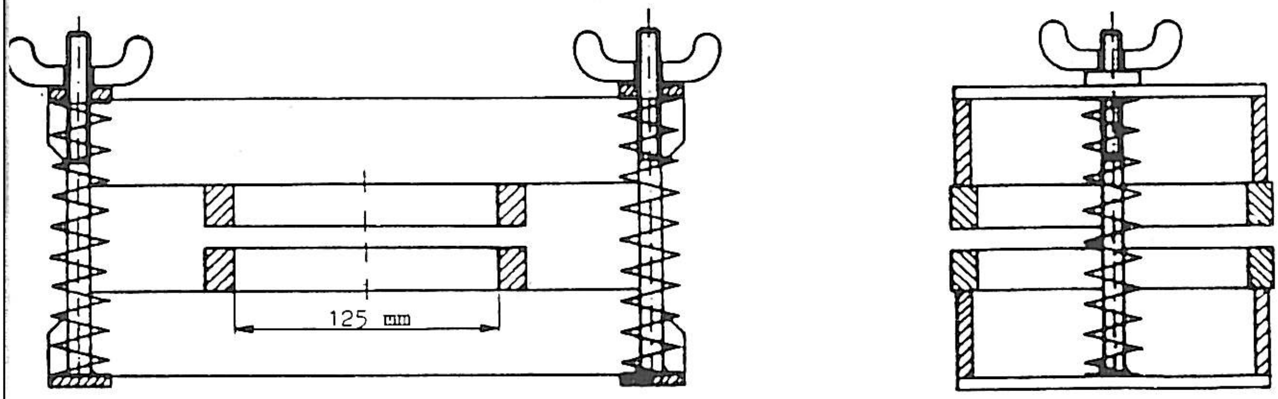
The machine is be operated at a speed of 50 mm/minute.

6.5 *Expression of results*

The pull-through strength is found for each fastener. The mean (X_m) and standard deviations for each series are calculated.

6.6 *Test report*

Use NBI-G01, paragraph 6.7, and include the elements applicable to this test method.



Longitudinal section

Cross section

Fig. 1. 125 mm diameter clamping ring

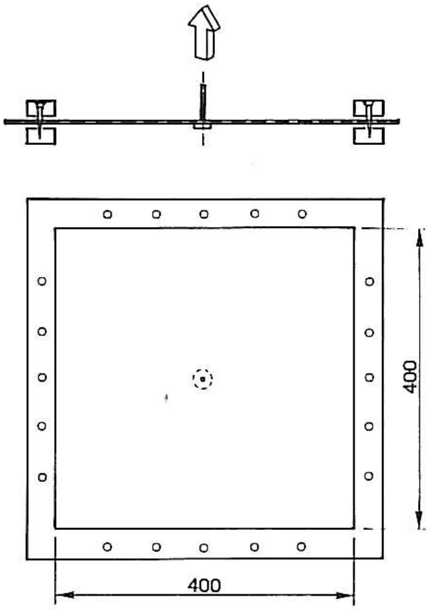


Fig. 2
Fastener pull-through

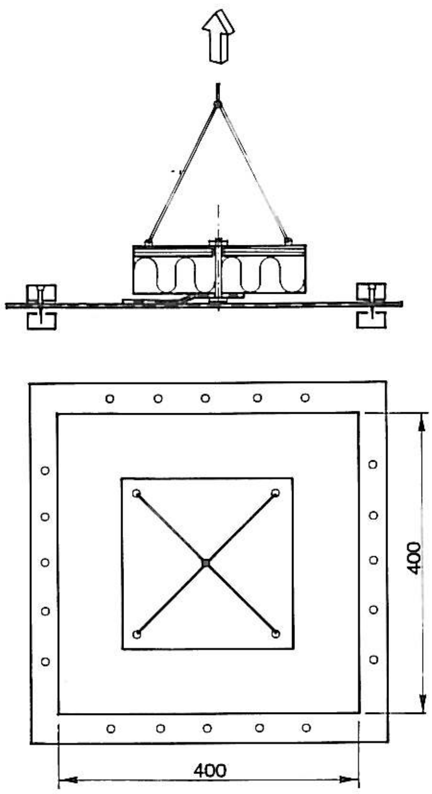


Fig. 3
Fastener pullout in flap

ROOF COVERINGS:
Dynamic loading strength of fasteners

1. SCOPE

This test method is designed to assess the strength of mechanical fasteners for roof coverings under the action of dynamic eccentric loading.

For testing under axially symmetrical, cumulative or pulsating loading, see NORDTEST method NT BUILD 306 Roof coverings: Strength of mechanical fasteners.

2. FIELD OF APPILICATION

This method can be used for all types of roofing fastener system.

3. REFERENCES

NBI Design Sheet, A544.206. Mechanically fixed roof coverings.

4. DEFINITIONS

A failure can occur in one or more of the following ways:

- breakage of the stress plate
- pull through of the shaft head in the stress plate
- permanent deformation which will destroy the load bearing function of the fastener

5. SAMPLING

As a rule, samples are tested as delivered. At least five samples are to be tested for each type of loading.

6. TEST METHOD

6.1. *Principle*

With the aid of a reinforced test strap, the fastener is subjected to a non-axical dyanmic impact from a free-falling weight connected to the strap by a steel wire.

6.2 *Apparatus*

- test rig as shown in i Fig.1
- wire-reinforced test strap (Fig. 2)
- drop weight with mass M (2 kg)
- device to measure the height drop, with marks every 100 mm

6.3 *Preparation of test samples*

The fasteners must not be prepared in any way, but it is important that the individual parts are in compliance with the manufacturers' instructions.

The preferred test temperatures with an accuracy of ±5 °C are +40 °C, +23 °C, ±0 °C and –10 °C.

6.4 *Procedure*

The dyanmic load can ble applied in the following ways.

A. Fixed drop height
The fastener is subjected to a dynamic impact with a specified drop weight of mass M (2 kg) and a fixed drop height in m to the nearest 0.1 m.

B. Intervals of increasing drop heights
Each fastener is subjected to impacts of increasing intensity. The drop height is raised in intervals of 100 mm until failure occurs.

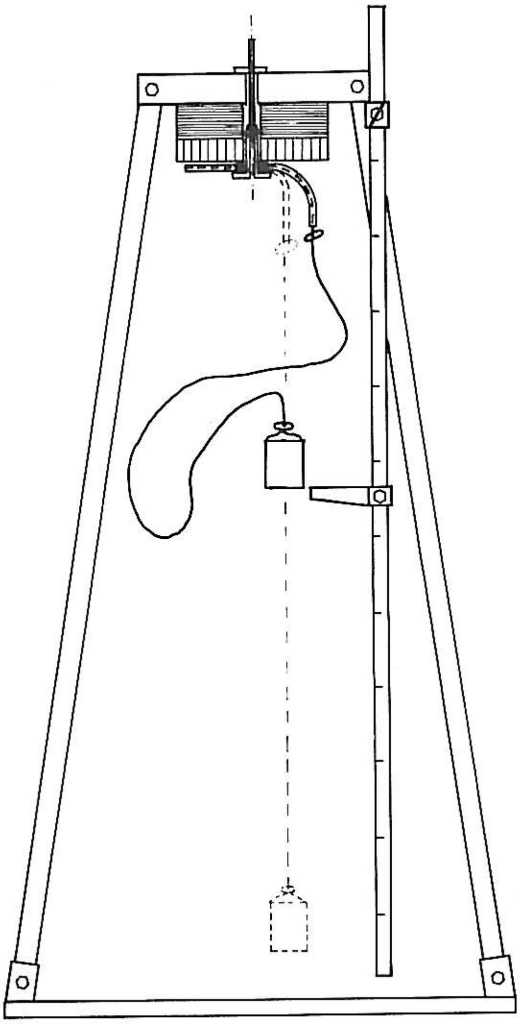
6.5 *Expression of results*

When the test is done using procedure A, the result is considered to be favourable when 3 out of 5 samples are without failure at the given height.

When using procedure B, the drop height at which failure occurs is recorded. The minimum height is given as the result.

6.6 *Test report*

Use NBI-G01, paragraph 6.7, and include the elements applicable to this test method.



1. Steel frame
2. 30 mm rubber pad
3. 50 mm wooden plank
4. Rod for measuring the height dropped
5. Reference height adjustments
6. Indicator for height dropped
7. Fastener
8. Test strap
9. Steel wire
10. Drop weight

Fig. 1
Rig for testing dynamic eccentric load on a fastener

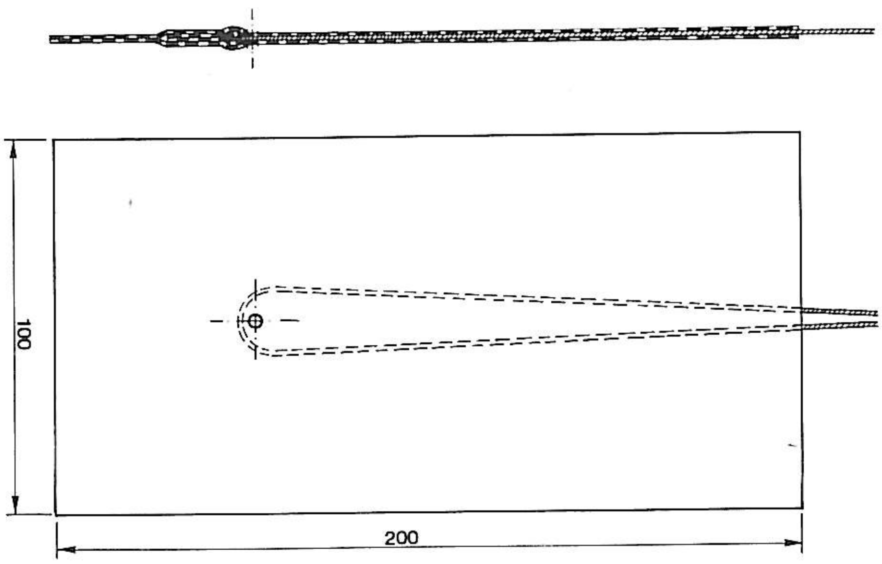


Fig. 2
Test strap with 2 mm diameter steel wire welded between two-ply 1.2 mm PVC membranes reinforced with PES fabric.