Built up roofs - wind uplift resistance

Built Up Roofs – Wind Uplift Resistance

Construction de toiture – Résistance de soulèvement au vent

Festigkeit gegen Windsaugkräfte von Dächern

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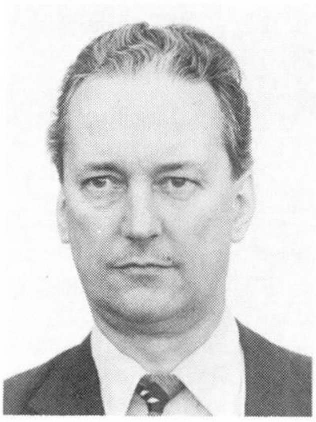

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SUMMARY

Results from laboratory and in situ tests with glued fasteners (steel deck – insulation – roofing felt) are presented. It is shown how to predict the «strength on the roof» from the laboratory test results. The roofs tested have been retested 8 years later with the same equipment and these results show that the strength has been reduced – in some cases to a very low level. The paper includes a theoretical analysis of the behaviour of mechanical fasteners and a comparison with tests.

RÉSUMÉ

Les résultats d'essais en laboratoire et in situ sur des toitures collées (tôle profilée – isolation – étanchéité) sont présentés. On y montre comment prévoir la résistance in situ à partir d'essais en laboratoire. Les toits testés ont été soumis à de nouveaux essais huit ans plus tard, avec le même équipement; les résultats montrent que la résistance a diminué dans certains cas jusqu'à un niveau très faible. Cette contribution comprend une analyse théorique du comportement des attaches mécaniques ainsi qu'une comparaison avec les essais.

ZUSAMMENFASSUNG

Labor- und Feldversuche mit Klebverbindungen (Stahlblech – Isolation – Dachhaut) werden beschrieben. Die Ergebnisse zeigen, dass es möglich ist, eine wirklichkeitsnahe Voraussage der Festigkeit mit Hilfe der Laborversuche zu machen. Die Dächer sind acht Jahre später noch einmal getestet worden. Diese Versuchsergebnisse zeigen eine Reduktion der Festigkeit. In einigen Fällen war diese Reduktion ganz erheblich. Schliesslich wird eine theoretische Berechnungsmethode mechanischer Verbindungsmittel und ein Vergleich mit Versuchen angegeben.

1. INTRODUCTION

An externally insulated sheet metal roof consists of load-bearing trapezoidal metal sheet, thermal insulation and a covering surface. The insulation and the surface covering can be fixed to the sheet either by means of mechanical fasteners or by asphalt. Earlier the insulation were traditionally fixed to the sheet metal by bonding with warm asphalt. Nowadays often mechanical fasteners are used. In the case of mineral-wool insulated roofs the washers for these fixing devices are placed on the lower felt layer or, in certain cases, directly on the insulation.

A lot of tests have been carried out during the last decade - both laboratory tests and in situ tests. Due to the large number of tests it has been possible to predict the "strength on the roof" from the laboratory test results. The roofs tested have been retested 8 years later with the same equipment and these results show that the strength has been reduced - in some cases to a very low level.

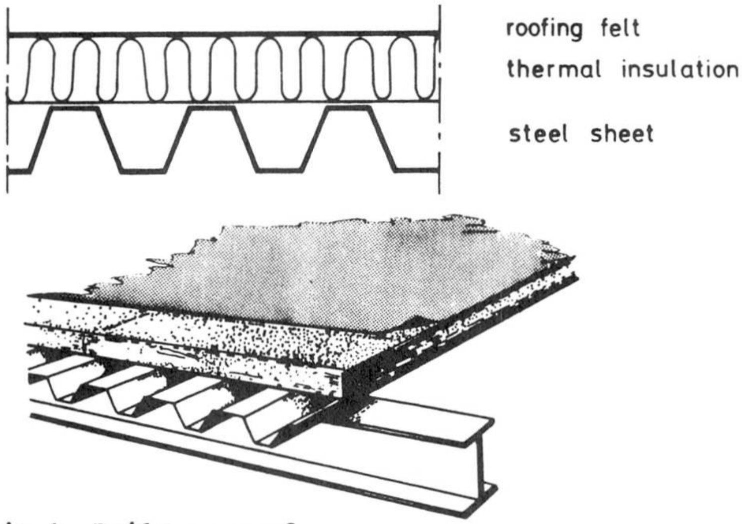

Fig.1 Built up roof

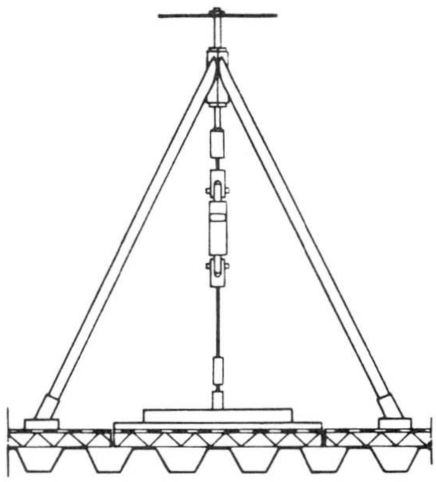

Fig.2 Test equipment for wind uplift testing

2. TEST EQUIPMENT AND TESTING PROCEDURE

The test equipment used consists of three main parts - a stand with lift outfit, a frame to be attached to the specimen and a dynamometer between the stand and the frame, fig.2. The stand is made of aluminium and wood. The liftning force is achieved via screw in the top of the stand. A 22 mm thick slab of chipboard was bonded with hot asphalt to the surface of the roofing felt. The width of the chipboard slab is 500 mm and the length is governed by the pitch of the steel sheet. After having glued the board slab and screwed the frame to the slab, the insulation and the roofing felt were cut along the slab lines. The test method is easy to handle but it has some disadvantages - the test surface is disturbed by cutting and by gluing with hot asphalt. However, some test roofs which showed very low strength have later blown off during storms and the roofs with high values for the strength have not done so.

It must be remembered that the test results are no more than values of the strength obtained by this test method. As far as reliability is concerned there is no doubt that roof with low measured strengths are exposed to a higher risk of damage than roofs with high measured strengths. Classification on the basis of the test results into roofs conforming to certain specifications and those which do not is a very doubtful procedure, and may easily lead to the wrong conclusions.

3. TEST RESULTS

In the middle of the 70's several roofs were tested with the equipment described. Twentyfive different roofs with insulation of fiber glass or mineral wool were tested with about ten specimens on each roof (200 in situ tests). The results showed a very large scatter, the maximum strength value obtained was more than twenty times the minimum value. The results are presented as a histogram in fig.3. The conclusion to be drawn is that the material quality and workmanship is not always what it ought to be. For instance, on one roof the lowest strength measured was 0.4 kN/m^2 and the highest 9.1 kN/m^2, a difference as high as 8.7 kN/m^2.

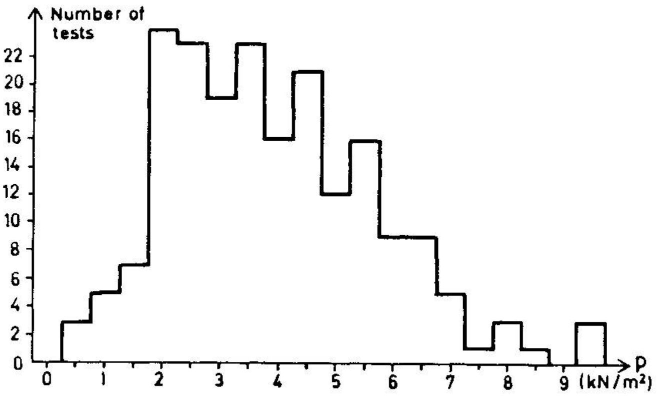

Fig.3 Measured strength of roofs with glass wool and mineral wool

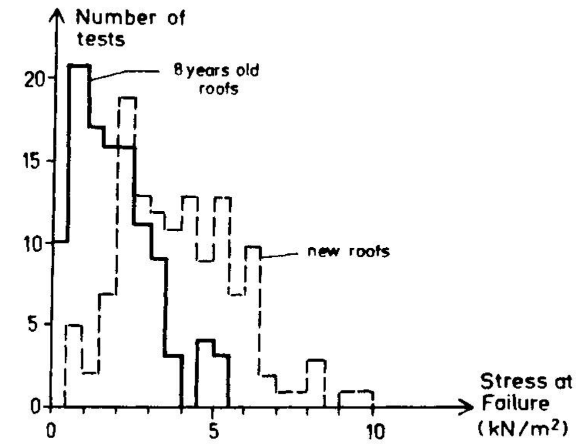

Fig.4 Measured strength of roofs with glass wool and mineral wool - comparison between old and new strength.

4. RETESTING

Eight years later, in the beginning of the 1980's, 13 of the roofs have been retested using the same equipment and the same technique. Some of the other roofs were "not available" for tests or they had blown off or they had been distroyed by fire. The results from the tests are a little bit frightening - there is a very large strength reduction. In table 1 some of the results are shown. After eight years the mean strength is reduced to about 50% of the original strength. The two histograms in fig.4 correspond to the measured strengths at all the roofs in table 1. The field tests show that for a new roof the fracture usually occur in the lower part of the insulation or between the insulation and the steel deck. Older roofs nearly always break in the upper part of the insulation just under the roofing felt.

Table 1 Measured wind uplift strength in kN/m^2 on roofs. The ratio in column (4) indicates the long-term strength reduction.

Roof no. (1)	Mean uplift strength 1974-75 (2)	Mean uplift strength 1982-83 (3)	Ratio (3)/(2) (4)
1	3,0	1,8	0,58
2	3,4	1,8	0,52
3	5,6	3,8	0,68
4	4,9	0,8	0,17
5	5,4	1,2	0,23
6	3,2	1,2	0,36
7	6,4	3,2	0,50
8	3,2	1,2	0,36
9	3,4	2,6	0,75
10	3,9	2,0	0,51
11	2,7	1,7	0,64
12	2,8	2,8	1,00
13	2,4	1,2	0,51
14	4,4	1,2	0,26

5. THE SHEETING SURFACE

Unevenness of the sheeting surface has some effect on the strength. There does not seem to be a definite relationship, but approximate scatter range can be discerned. The relationship between strength and the measured deviation over three corrugations, Δ_3, are plotted in fig.5 for 18 roofs. The conclusion which can be drawn from these figures is that a more even roof surface may increase the short-term strength, but need not necessarily do so.

6. DIFFERENT TEST METHODS

The wind uplift strength depends mainly on two parameters - the strength of the insulation and the strength of the bonding between the insulation and the steel deck/roofing felt.

In pure material oriented laboratory tests only the insulation values are given. Several laboratory tests have also been made on specimens representing a cut-out part of a full roof.

It may be stated that a more realistic test method will lead to a lower measured strength. From several tests (≃ 200 specimens or more per group) the approximate relationship as shown in fig.6 were obtained. This means that after some years in service one may expect a rather low strength of the roof. If the initial strength is 10 kN/m^2 this value is reduced to about 1.5 kN/m^2 after a period of approximately 10 years in service. The risk for storm damages increases. The figures given above are mean values.

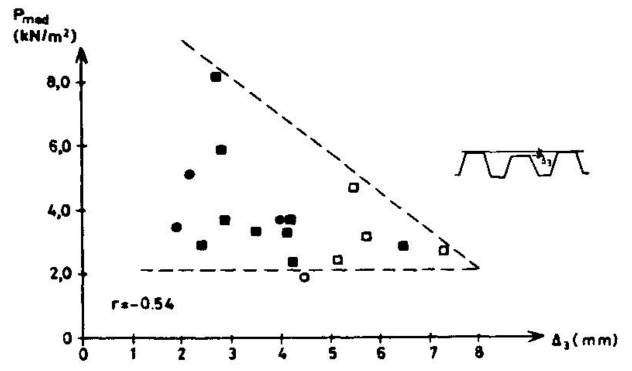

Fig.5 Relationship between measured strength (failure at sheeting - insulation interface) and measured flatness deviation Δ_3 for roofs insulated with mineral wool.

TEST METHOD	RELATIVE STRENGTH
Material test	1.0
Laboratory test	0.6
Field test new roofs	0.3-0.35
Field test old roofs	0.15

Fig.6 Dependence of strength on the test method

7. MECHANICAL FASTENERS

Storm damages due to the low strength have led to a new concept. Instead of using asphalt bonding most of the roofs nowadays have mechanical fasteners. This means that the requirements on the steel deck have been reduced and that the roof behaves in a different way. The use of mechanical fasteners on roofs have led to very few storm-damaged roofs. There are many different types but most of them consist of a screw and a washer. The fasteners are placed in a rectangular net, fig.7.

"Full scale tests" with suction box have shown that there is not linear relationship between the limit load and the number of screws mer m^2 if fracture occurs in the attachment between the water proofing membrane and the fastener. Usually fracture appears to be a combination of bending in the washer and punching of the membrane. The washer and its perimeter can be divided in four different parts where

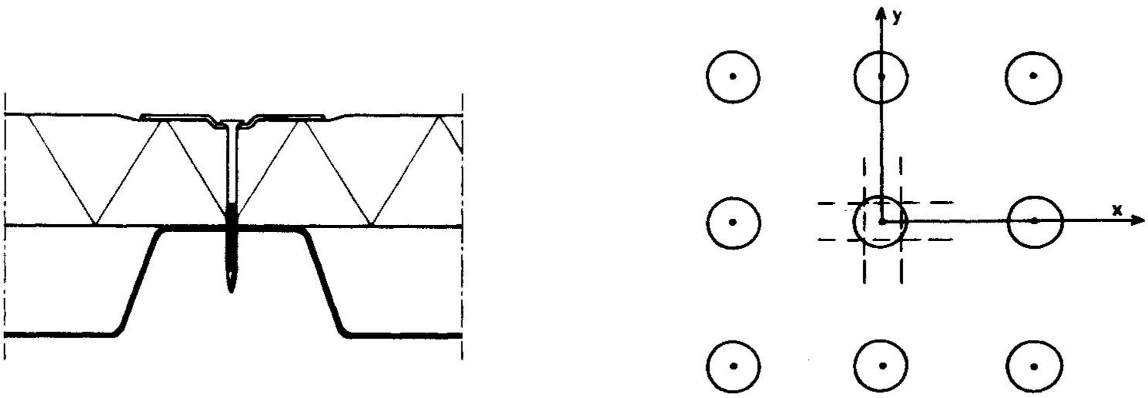

Fig.7 Mechanical fasteners. Possible folding lines for the washers are indicated.

the boundary between the areas inclines 45° degrees to the attachment lines. The load on the screw, the total force, is the sum of all the loads on the different areas, I-IV, fig.8. The maximum load of the fastener occurs when the load on any of the perimeters I, II, III, IV reaches its maximum (fracture) level. If the exterior load is assumed to be carried the nearest way from the membrane to the fastener we get the influence areas shown in fig.9. When the external load q causes fracture in the fastener the load on perimeter II is

$$P_{II} = q \cdot \frac{a}{2} \left(b - \frac{a}{2}\right) \quad (1)$$

The corresponding load at perimeter I is

$$P_I = \frac{a/2}{(b-a/2)} P_{II} \quad (2)$$

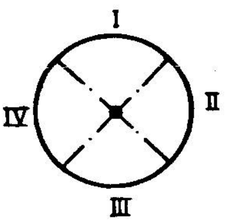

Fig.8 Washer

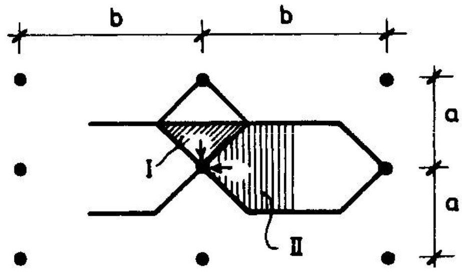

Fig.9 Influence areas. Area I = $a^2/4$

The total load on the fastener at rupture can be expressed as

$$P_{fast} = P_{II}(2 + a/(b - 0.5\ a)) \quad (3)$$

The maximum load for the fastener is reached for a = b and P_{max} is $4P_{II}$. The ratio a/b is governing the maximum load in the fastener and in fig.10 the ratio P_{fast}/P_{max} is shown.

$$P_{fast}/P_{max} = 0.5 + 0.5/(2\ b/a - 1) \quad (4)$$

From eq (4) you will find that doubling the number of fasteners by changing from a quadratic net a x a to a rectangular net $\frac{a}{2}$ x a will raise the external load by 33%. (P_{fast}/P_{max} decreases from 1 to 0.67) There have been conducted tests |2| on different types of membranes and different spacings. Those results can be said to confirm the thoughts behind equation (4). In table 2 are given the theoretical and measured load ratios for four different membranes with the results from the specimen with a = 0.4 m as reference value. The theoretical values are the ratios between the influence areas. The membrane types 2 and 3 are fastened in a different way – that is why the ratios differ a little even for the same values of a and b. With regard to the fact that the number of tests is small one must say that there is a fairly good agreement between theory and practice.

Table 2 Comparison between calculated and measured load ratios, P_{fast}/P_{max}. The results from the specimen with a = 0.4 are used as reference values.

Membrane	b m	a m	Theory	Measured
Type 1	0.9	0.4	(1.0)	(1.0)
		0.6	1.29	1.31
		0.8	1.43	1.62
Type 2	0.9	0.4	(1.0)	(1.0)
		0.6	1.21	1.21
		0.8	1.31	1.34
Type 3	0.9	0.4	(1.0)	(1.0)
		0.6	1.21	1.24
		0.8	1.31	1.40
Type 4	1.2	0.4	(1.0)	(1.0)
		0.6	1.35	1.27
		0.8	1.6	1.53

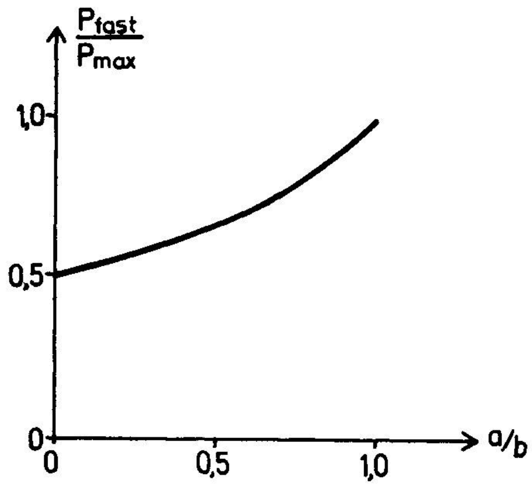

Fig.10 Maximum load in the fastener as a function of a/b

8. CORROSION

Fasteners on 14 different roofs, all situated on the Swedish West Coast have been examined. Totally 134 (≃ 10/roof) screws + washers have been removed and examined. The average age of these roofs was five years. Some little rust was found on 5% of the examined screws but no serious corrosion was found. No corrosion at all was found on the steel deck. The investigation indicates that corrosion of screws is not a great problem.

9. CONCLUSION

This paper is a summary of several research projects into the strength of built-up roofs against wind suction. The main conclusion is: Be careful with asphalt glued design — use mechanical fasteners (if possible equally spaced) instead.

10. REFERENCES

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