Roof failures due to ponding – a symptom of underestimated development

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In the Netherlands about 20 light-weight flat roofs collapse every year as a result of ponding of rainwater during heavy rain showers. Despite the fact, that in 1993 a new regulation came in force (Dutch Bouwbesluit) addressing the rainwater ponding on the light-weight flat roofs, the roofs built after this date continue collapsing seemingly in the same rate. From reports made by different institutions and bodies on these and other construction failure related subjects, it can be concluded that the collapses of light-weight flat roofs do not stand alone. They are one of the symptoms of a larger development on the building and construction market in the Netherlands. A development that is characterized by emphasis and focus on pushing the structural limits in order to save materials and costs in combination with declining priority concerning coordination, checking and site supervision. Also deregulation, resulting in less control instruments and procedures in practise and fragmentation of the design and construction processes, play here an important role.

Key words: Light-weight flat roof, rainwater ponding, structural failures, structural safety

1 Introduction

An investigation [1] carried out on behalf of the Dutch Ministry of Housing in 2002, reveals that in The Netherlands about 20 light-weight flat roofs collapse every year as a result of ponding of rainwater during heavy rain showers. Despite the fact, that in 1993 a new regulations came in force (Dutch Bouwbesluit) addressing rainwater ponding on light-weight flat roofs, the roofs built after this date continue collapsing seemingly in the same rate (Figure 1). Until recently the extent of these failures was not fully recognized. The failures were mostly seen as solitary accidents caused by extreme weather conditions that could not be reasonably accounted for, such as local whirlwinds forming during heavy thunderstorms. Seeking the cause behind an extreme wind loading, rather than behind a water accumulation, was often supported by the form of the collapse, where the collapsing roof was inflicting a considerable damage also to the façade of the building. Also the fact that most insurance policy's cover damage caused by a wind storm with a wind force 7 Beaufort or above and do not cover damage caused by ponding [3], may be a reason why many owners of the buildings, who were confronted with such a damage, were more inclined to see the wind as the cause [2].

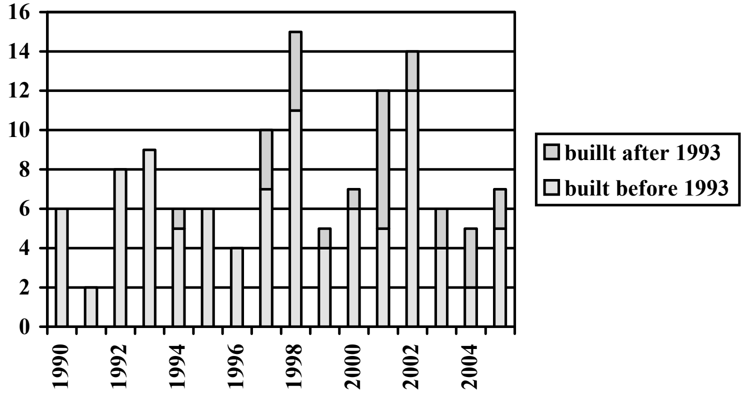

Figure 1: Number of light-weight flat roofs yearly collapsed in the Netherlands due to rainwater ponding. 50% of the total estimated. (Source: Hageman [1])

Out of investigations carried out by the Dutch Ministry of Housing in 2002 and published in 2003 in a report [3], the conclusion can be drawn, that the phenomenon of collapse of light-weight flat roofs during heavy rain showers is not new. Although not new, there has been no systematically registration of these failures made until recently. It appears that mainly light-weight flat roofs (e.g. roofing membrane and thermal insulation on structural steel roof sheeting supported by a steel structure) are susceptible to water accumulation and subsequent collapse. This type of roof structures is mostly used in industrial halls, but also in buildings with public functions like swimming pools, sports halls, department stores and shopping centers. In all cases that were investigated by the Ministry, the failures of the roofs were primarily caused by errors in design or execution. The reasons can be summarized as follows:

- The designers are not always sufficiently aware of the dangers and risks of rainwater accumulation.
- The code requirements are not always followed, the code is often experienced as too complicated.

- The execution does not always comply with the approved drawings and details.
- In the building process, from the initiative and design to the handing over and maintenance, there is a lack of an adequate quality assurance system aimed at preventing of the above.

In all investigated cases, it appeared that the code requirements [7] sufficiently cover the occurring loads and the circumstances under which these loads act on the structure. But it is the roof structure (and the roof detailing), that on one or more aspects does not comply with these code requirements.

2 Actions by Government

The number of roofs collapsing every year and the extent of related damage lead the Dutch Ministry of Housing (VROM), among others, to take the following steps:

1. All companies in The Netherlands, with more than 10 employees, received in May 2003 a letter [12] from the Ministry, pointing out to them the risks of rainwater ponding. Enclosed to this letter was a scheme (checklist) with instructions, set up for fast assessment of roofs with regard to a possible increased risk due to rainwater ponding. Sloped roofs and heavy (concrete) roofs were indicated as roofs without any risk. Light weight flat roofs were categorized as roofs with a potential risk, depending on the following factors:
   - rainwater overflow system present or not
   - rainwater overflow system in accordance with the code regulations or not
   - roof slope <1,5%, or >1,5%
   - changes to the roof during its lifetime
   - regular inspections of the roof or not
   - the results of these inspections

2. All Municipalities in the Netherlands were ordered by the Ministry to make an inventory of all buildings in their property that are open to public and have light-weight flat roofs and inspect and check these roofs on risks regarding water accumulation and safety. Regardless whether Municipal property or not, also other buildings open to public had to be included in this inventory. The Municipalities were left relatively free in how to organize this action.

3. The Municipalities were made aware of their responsibility with regard to building permits and the supervision on site and on the fact that a building permit application for a light weight flat roof without an adequate calculation of rainwater ponding has to be rejected.

4. The Ministry has initiated and facilitated the development of a design and assessment tool – *"NPR 6703, Ponding on flat roofs caused by rainwater, - simplifying supplement to NEN 6702"* [6] – in the market to simplify the calculations and the assessment of flat light weight roofs for rainwater ponding. This design and assessment tool is in the mean time in use.

3 Flat roofs inventory and inspections in practise (example)

As a result of the Minister's writing to the Dutch Municipalities and companies to inspect and check the flat roofs for risks regarding water accumulation and safety, consulting engineering firms have been commissioned by different owners and (Municipal) authorities to make an inspection of and report on several hundreds of flat roofs [8]. These inspections, reporting and where applicable supporting check calculations, to check whether the roofs comply with the code requirements of the Dutch code NEN 6702 Technical principles for building structures – TGB 1990 – Loadings and deformations [7], were carried out in the period 2004 – 2006.

The first step in this process was to check the roofs for the following:

- In the Municipal inventory: is the inspected object open to public or not? If not, the roof did not need to be inspected.
- Then in all cases: has the object a (large) light-weight flat roof? Every roof with a slope <5% was considered to be a flat roof. As light-weight were considered aluminum, steel structure or timber roofs, with aluminum or structural steel roof sheeting, cellular light-weight concrete panels, or timber roof panels. The roofs falling outside the qualification flat or light-weight, were considered as not sensitive to influences of rainwater ponding and were not further inspected.

The roofs that were not eliminated by the above described first check were subjected to a visual inspection. Inspected, measured and registered in a report was the following:

- shape and dimensions of the roof
- slopes
- dimensions of the roof upstands
- position and the dimensions of the regular rainwater discharge inlets
- position and the dimensions of the rainwater overflow openings if any
- short description of the roof structure
- changes in the roof structure (information by the caretaker / building management)
- past damage (information by the caretaker / building management)
- roof maintenance and cleaning (information by the caretaker / building management)
- intervals of regular inspection if any (information by the caretaker / building management)
- state of the roof: clean , presence of rubble, plants, rainwater ponding, traces of rainwater ponding, blocked rainwater discharge inlets, etc. When considered of importance, this was supported and documented by digital photographs. See Figures 2, 3 and 4.

The results of the inspections that have been carried out can be divided in the following four main groups (see also Figure 5):

A/ *No visual inspection carried out.*

Objects falling in this group, have a roof that is either not flat, not light-weight, or the object is not open to the public.

B/ *Roof complies with the requirements, no further (check) calculations needed*

Objects in this group had in general roofs with sufficient slope, no or very low upstands, and / or such a detailing, that it was obvious that rainwater ponding was out of the question. (See for example Figure 6).

Figure 2: Rainwater ponding, no emergency overflow in the roof up stands

Figure 3: Plant growth and fallen leafs on the roof

Figure 4: Light street blocking the roof slope results in ponding

C/ *Additional check calculations necessary*

In this group objects with roofs were placed, where without detailed (check) calculations, it was not possible to establish whether the roof and its structure comply with the code requirements. These were roofs with a small slope and doubts about the detailing and the dimensions of the rainwater overflow openings, their functioning, etc.

D/ *Roof does not comply with the requirements*

In this group objects were placed where it was obvious that the roof does not comply with the code requirements. In most cases the emergency rainwater overflows were missing. In case of blocked regular rainwater discharges, here an excessive rainwater accumulation was possible.

It has to be noted that for the roofs falling in category D, although these roofs do not comply with the code requirements, the danger of roof collapse due to rainwater ponding does not need to be imminent.

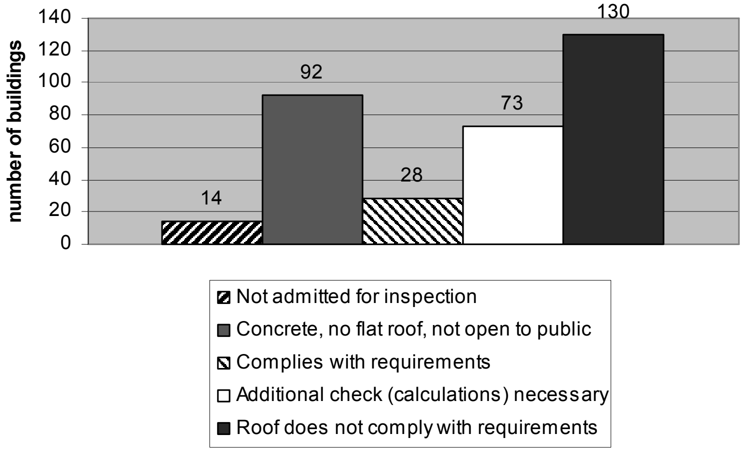

Figure 5: Inspection results for objects with flat roofs
(Inspections carried out in the period 2004 – 2006)

Figure 6: An example of light-weight flat roof where already the detailing only (elevated trough roof sheeting under sufficient slope in combination with lower positioned roof gutters) prevents any form of rainwater ponding that could impair the structural safety and quality of the roof

It is also clear, that for the roofs in category C and D, that do not comply with the code requirements, calculations have to be made to determine the measures that are necessary to take for improving these roofs. For such calculations, detailed data of the roof structure have to be available, such as steel sections used, steel grade used, etc. This is however not always the case, or is unproportionally difficult to obtain.

In such a case, the minimum live load requirements prescribed by the code in force for the steel roof in question in the time of its realization, offer a solution. This live load can be translated to a layer of water with a depth "d". Emergency overflow intakes can then be placed in the places of the expected lowest deflections of the roof with dimensions and detailing designed for rainwater levels not to exceed the calculated depth "d". See also [6] NPR 6703, Ponding on flat roofs caused by rainwater, - simplifying supplement to NEN 6702.

4 Rainwater ponding on roofs

The phenomenon of rainwater ponding can be explained by an example of a completely horizontal flat roof without upstands, with an initial deflection caused only by its own weight [4] [5]: Rainwater falling on such a roof will first concentrate in the deflection caused by the own weight of the roof, with as a direct consequence an increase of this deflection, subsequent additional rainwater ponding etc. etc. Depending on the strength and stiffness of the roof this can result in the following two situations:

1. Every additional quantity of rainwater will cause a deflection that is bigger than the thickness of the rainwater layer causing this deflection. This means that the rainwater falling on the roof will flow towards the deflection, the additional weight of the water increasing the deflection further and so on and so on. Rainwater flowing over the edges of the roof will not take place. This will continue until either the rain stops, or the ultimate bearing capacity of the roof will be reached and the roof will collapse.
2. Every additional quantity of rainwater will cause a deflection that is smaller than the thickness of the rainwater layer causing this deflection. This means, that at a certain moment, provided that the ultimate load bearing capacity of the roof is not reached, equilibrium takes place, the deflection does not increase anymore and the additional rainwater falling on the roof flows over the roof edges.

Based hereon a requirement can be formulated as follows:
A roof structure has to be designed in such a way, that no ponding of rainwater can take place resulting in a structural failure or permanent deformation of the roof or its parts.

Important factors are here:

- Sufficient stiffness of the roof and its components.
- Sufficient rainwater discharge possibilities. In case of malfunctioning of the regular rainwater discharge system, an adequate overflow system has to be present. The strength and stiffness of the roof and its components has to be designed, detailed and executed keeping in mind the maximum overflow water levels.
- Sufficient roof slope and or camber.
- In addition to the above, in design of the light flat roofs it is important to consider the following:
- The requirements given in the codes and standards are **minimum requirements.**

- Every roof will have erection inaccuracies with regard to levels, slope and the exact levels of the rainwater discharge openings.
- The dead load of the structure and permanent loads on the structure are only estimates of the real loads.
- The schemes and models used in the static calculations never represent the exact reality "as built".
- There are always differences in foundation deformations.
- The flow of water on the roof can be influenced by the wind.
- The flow of (rain)water on the roof depends on the slope of the water surface, the rain intensity, the roughness of the roof surface, the roof slope, presence of hail, snow and fallen tree leaves.
- The quantity of water that can flow to the ponding area is dependent on the size of the roof area that can supply this water.

From the above it is quite clear, that for a quantitative assessment of roofs with regard to rainwater ponding good insight in and understanding of the roof deformation behaviour is needed. For an appropriate design of roofs, also a good knowledge of practical and appropriate detailing can be very helpful and effective (see Figure 6).

5 The cause of failures due to rainwater ponding

The processes, where things can go wrong, can be positioned in three levels [10]: the micro-, meso- and macro level:

- To the *micro level* belong human errors, like mistakes, wrong analysis, insufficient knowledge and such alike.
- On the *meso level,* aspects are found like management and organization of projects and processes, together with the related communication.
- To the *macro level* belong the "building construction culture", education, law, code regulations and comparable.

Rainwater accumulation is almost always the result of one or more of the following factors.

On micro level [3]:

- insufficient roof slope

- insufficient capacity of the rainwater discharge system
- insufficient stiffness of the roof structure

Most of the above factors have their origin in incorrect or erroneous design. Also incorrect execution, such as wrongly positioned, less than designed, or no rainwater overflows (emergency discharge), no or wrong roof slope, no or wrong camber, columns not correctly levelled, lighter roof sheeting or lighter roof structure than in the original design, is often to blame.

The Ministry gives in its report [3] the following overview of the factors that were playing a role in the roof collapses that were investigated. All these aspects belong to the micro level. The subjects, that are mostly design related, are here indicated in italics:

Insufficient capacity and / or not good functioning of the regular rainwater discharge system	80%
No or insufficient number of rainwater overflows or wrongly positioned rainwater overflows	84%
Insufficient roof slope	55%
Too small or no camber of the roof beams	18%
Insufficient stiffness of the roof structure	44%
Insufficient strength of the roof structure	21%
Other reasons	8%

On meso level:

- Construction industry processes are predominantly price-driven, instead of quality-driven. This applies as well to the design as to the execution [10].
- Insufficient quality assurance [3] [4] [9].
- Declining importance of coordination, checking, control and site supervision [9],[10]

Based on their research, CUR [10] and OVV [9] report, that the above mentioned factors of the meso level are representative for all fields of the whole construction industry and the related processes.

On macro level:

In all cases the relevant code regulations are found adequate. The loads the structures have to be designed for, and other requirements prescribed by the codes in order to prevent the structures from collapsing, are adequately representing the situations to which the structures can be exposed during their life time. The users however, experience some code regulations or their parts, as too complicated to follow [3]. Code regulations concerning rainwater ponding on light weight flat roofs, are such regulations. The fact is, that the effects of ponding are often not, or insufficiently included in the static calculations of the structures. Insufficient quality insurance and declining importance of coordination, checking, control and site supervision on the meso level make such omissions undetected.

The Dutch Council for Safety (Onderzoeksraad voor Veiligheid, OVV) observes in the conclusions of its report [9] among others, that the designers and builders are submitting plans and documents for governmental approval, which they themselves did not, or did not sufficiently, check. The same is observed in the open letter [11]written to the Ministry of Housing (VROM), by the institutions in which in The Netherlands most of the building and construction professionals are organised. It is important to note here, that the Governmental authorities are not supposed to do the said checking. It is the work of the designers and builders. The Governmental authorities are not equipped for this task. In both documents it is therefore recommended to the Minister, to adjust the building permit conditions and to make an appropriate and evident checking and quality assurance control by the principals, designers and builders a part of these building permit conditions. If necessary, it is recommended to the Minister to adjust the law accordingly.

Further, it can be observed, that in the last decades the building industry was mainly focussed on far fetched refining of structures and pushing the structural limits in order to save materials and reduce costs. This trend was enhanced by the revolutionary developments in the field of computational facilities. On the other hand the societal and political call for deregulation has in the same period resulted in less control instruments and procedures in building. These two developments are incompatible and their incompatibility contributes strongly to the situation the Dutch construction market is confronted with today also there, where it comes to ponding of rainwater on light weight flat roofs.

From the above, it can be concluded, that although the technical code regulations are adequate, on the macro level there are obviously aspects present that have an adverse influence on the structural safety and quality of building structures. This also holds for light-weight flat roof structures and contributes to their collapsing due to rainwater ponding.

6 Conclusion

From the above it can be concluded, that the collapses of light-weight flat roofs due to ponding do not stand alone. They are one of the symptoms of a larger development in the building and construction market in the Netherlands. A development that is characterized by:

- Emphasis and focus on pushing the structural limits to save materials and costs.
- Declining the importance of coordination, checking, control and site supervision.
- Deregulation, resulting in less control instruments and procedures in the building processes.
- Far reaching fragmentation of the design and construction processes.

This development has set in already decades ago and remained for a long time unnoticed with regard to its enhancing negative influence on the structural safety and quality of building structures. It has affected the structural safety and quality in all fields and on all levels of the Dutch building and construction market. Light-weight flat roof structures form only a part of it.

References

[1] Jong, P. de, "Dakinstortingen door wateraccumulatie," (Roof collapses due to rain water ponding", in Dutch), Dossier 4881, Adviesbureau ir. J.G. Hageman B.V. , Notitie 31-10-02 and 12-01-2006,

[2] "Instorting Het Kubus" ("Collapse Het Kubus", in Dutch), Corsmit Consulting Engineers, Report nr. W84440, 1993

[3] Kool, E.J., Kolner, W.P.P., Meer J. van der, "Instortingen van lichte platte daken", ("Collapses of light flat roofs", in Dutch), VROM Inspectie (Ministry of Housing, Inspection), Distributienummer 15056/177, February 2003.

[4] "Wateraccumulatie een incident of een structureel probleem" ("Ponding due to rain water, an incidentally or frequentally occurring problem", in Dutch), Bouwen met Staal, 18 June 2003

[5] "Vervormingseisen voor bouwconstructies (rapport 2) ("Deformation requirements for building structures (report 2)" (in Dutch), Staalbouwkundig Genootschap, CUR, September 1975

[6] Nederlandse Praktijkrichtlijn (Dutch Guidelines for Practice) NPR 6703, Wateraccumulatie – Aanvullende rekenregels en vereenvoudigingen voor het belastinggeval regenwater in NEN6702 (Ponding on flat roofs caused by rainwater – Supplementary to NEN6702 with additional and simplified rules, in Dutch), NEN, Delft, the Netherlands, 2006

[7] NEN 6702 Technical principles for building structures – TGB 1990 – Loadings and deformations.

[8] "Onderzoeksrapport project Platte daken Den Haag" ("Investigation Report Project Flat Roofs The Hague", in Dutch), Corsmit Consulting Engineers, Report nr. W29950 WE-R901, Rijswijk, 20-05-2005

[9] "Veiligheidsproblemen met gevelbekleding", ("Safety problems with facade claddings", in Dutch), Onderzoeksraad voor Veiligheid OVV (Dutch Council for Safety), the Hague, 23 november 2006

[10] "Leren van Instortingen" ("Learning from collapses", in Dutch) Civieltechnisch Centrum Uitvoering Research en Regelgeving CUR Report phase 1 , June 2005

[11] Open letter to the Ministry of Housing (VROM) "Schade in de Bouw" ("Damage in the building Industry", in Dutch) by TU Delft, ONRI, BNA, KIvI, COB, KIWA, ref. JV, dated 11-11-2003.

[12] "Instorten van platte daken" ("Collapsing of flat roofs", in Dutch), VROM-Inspectie (Ministry of Housing, Inspection), Letter 7064/koln/veld, dated May 2003