Water Discharge Systems and Modelling of Rain Water Discharge at Nidaros Cathedral, Trondheim, Norway

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Abstract

This paper deals with the water discharge system at Nidaros Cathedral, Trondheim, Norway. It is shown that the present water discharge system is unable to cope with heavy rainfall, but also that freezing-thawing resulting in leaks is of greater importance with regard to weathering, than flooding in parapet gutters and other parts of the system. A spread sheet model has been developed for calculating capacities and dimensions of gutters and downpipes. Calculations indicate that the capacity of the present water discharge system should be increased by 2-300%. In order to avoid significant alterations of the architecture, it is proposed to repair, extend and maintain the present water discharge system, rather than to undertake larger reconstruction measures.

Introduction

Nidaros Cathedral, the northernmost of Europe's medieval cathedrals, has for decades had problems with water leaks resulting in weathering of exterior and interior stonework. These problems, especially those related to serious salt weathering, have been described by Storemyr (1997). In this work an underdimensioned, poorly maintained and only partly working water discharge system was held responsible for the majority of observed damages.

In order to verify these alarming observations and obtain a basis for eventual redesign of the water discharge system, a joint project between The Restoration Workshop of Nidaros Cathedral and the engineering company Grøner Trondheim was undertaken in 1999-2000. This project was part of the larger EU Raphaël project at Nidaros Cathedral, which was undertaken in order to obtain a scientific basis for the planned restoration of the cathedral (Storemyr & Lunde

Figure 1: The chancel at Nidaros Cathedral in wintertime. Note the icicles.
1998). Based on observation and modelling of rainwater discharge, the project aimed at finding the weaknesses in the system and, furthermore, to calculate capacities and dimensions for gutters, downpipes and gullies.

Situated in Trondheim in Middle Norway, Nidaros is probably the European cathedral most heavily influenced by snow and frost. Thus, considerations about how to deal with disposal of snow and freeze-thaw problems have also been included in the project.

This paper primarily deals with the gothic (or "neogothic"), basilical parts of the cathedral, especially the three-aisled chancel and nave that were partly reconstructed and completed in 1890 and 1930, respectively. The water discharge systems, weathering problems and suggestions for improvements at the romanesque parts have been thoroughly described by Storemyr (1997). The paper neither deals with water discharge from downpipes and gullies to the ground around the cathedral. It is presupposed that in a redesigned system, downpipes ought to end somewhat above the ground (in order to ease inspection) and the water led to a closed drainage system. Such a system exists around the cathedral, but it is partly blocked and does not work properly.

In order to place Nidaros Cathedral in an European context, some general remarks on water discharge systems at medieval cathedrals, supplemented by our own observations, will be given first.

**General remarks on water discharge systems at medieval cathedrals**

According to Hans-Georg Lippert (1994), the gothic (13th-14th century) water discharge systems were integrated parts of the architecture and not, as is normal today, secondary disposal systems that can be maintained and replaced “independently” from the building. This implied that gutters and pipes were usually made from dense stones (dense limestone, basalt...
etc.) and joints with hard mortars or lead. Coverings of lead or copper were usually not applied.

This last observation probably also holds for parapet gutters - one of the important gothic innovations. Parapet gutters were perhaps mainly intended to collect rainwater in a controlled way, which was needed due to the complex geometry of gothic cathedrals. Earlier, at simpler Romanesque buildings, water mostly discharged freely over the eaves. Moreover, parapets also enabled the gothic builders to inspect and maintain roofs at very elevated levels.

None of the known water discharge systems at gothic cathedrals on the European continent brought the water directly to the ground by means of, for instance, downpipes or similar constructions (ibid.). The systems usually ended with a gargoyle or a gully at the height of the aisle cornice. The resulting water splash at foundations, windows and masonry was obviously looked upon as unavoidable, although cornices and stringcourses helped disperse the water. However, there are several examples of the use of various types of shaft-like pipes built into buttresses and walls, but such systems were only applied above the aisle (i.e. the cathedrals in Regensburg and Bayeux). In England, Bond (1906:113) mentions an example of the use of leaden downpipes at King’s College Chapel in Cambridge in the 13th century, but this was probably a rare exception employed in order to save newly whitewashed walls from discoloration.

Lippert (op.cit.) also maintains that gothic water discharge systems were unable to work over longer periods of time without regular inspection and maintenance. He suggests that the construction of such systems implicitly assumed the further existence of a Workshop able to deal with regular repair.

In addition to several local and particular techniques, there were in principle two main solutions to the water discharge problem at gothic cathedrals; either joint or separate discharge from main roofs and aisle roofs (ibid.).

**Joint discharge** means that water from the main roofs is discharged by gargoyles and gullies from the main roof/parapet to the aisle roof(s) and further down to the ground by a similar system. According to Bond (1906) and my own observations, variations of this system can especially be found in England. One of the reasons appears to be that English cathedrals are quite low, implying that the risk of damage to walls and aisle roofs due to water splash is rather limited.

At the generally higher French cathedrals it seems that it was more common to apply **separate discharge** of water from main roofs and aisle roofs. This was only possible at cathedrals with flying buttresses, which were put in use as small "aqueducts", in which water from the main roof/parapet could flow to gargoyles or gullies discharging it at the ends. Usually, water from the parapet was...
brought to the flying buttresses by means of closed or half-open stone pipes. Water from the aisle roofs was discharged by means of gargoyles or gullies as in the case of joint discharge systems (Lippert, op.cit.).

Although the separate discharge system is regarded as a highlight of gothic architecture, it is still today easy to observe that also this system has its limitations. For example, at Notre Dame in Paris, the water that is discharged hits stone decorations below, which as a consequence weather rapidly. Whether or not this is a problem at other cathedrals is of course dependent on the architectural design. Moreover, all systems designed to freely discharge water by means of gullies or gargoyles might be dangerous with regard to destruction of stonework (and stained glass windows) below. In addition, one has to consider the formation of icicles in colder climates.

These problems are probably the reason why many, perhaps most, gothic water discharge systems were replaced or extended by metal downpipes during the restorations in the 19th century (or earlier/later). By means of downpipes it is much easier to control the water discharge, but at the same time a rather unsightly element was introduced to the cathedrals. Moreover, also downpipes have their limitations – they tend to be blocked by leaves and other rubbish if not maintained properly. In cold climates they may also be blocked by snow and easily destroyed by ice formation.

According to our observations most modern water discharge systems employing downpipes are joint systems. This means that downpipes from the main roofs/parapets discharge the water either on the aisle roofs or directly into aisle parapet gutters by means of downpipes continuing over the aisle roofs. In many cases the old gargoyles and gullies function as overflow systems when there is heavy rain or the downpipes are blocked. It is

![Figure 4: The chancel at Rouen cathedral with its modern joint water discharge system based on downpipes. Note flying buttresses with "aqueducts", which formed the original discharge system](image-url)
noteworthy that most downpipes observed at European cathedrals appear to be well dimensioned, or rather “overdimensioned”, implying that the systems are not blocked up that easily.

Table 1: Present main water discharge systems at a number of European cathedrals, as observed by the authors. Note that several cathedrals may have additional systems as well

<table>
<thead>
<tr>
<th>Country</th>
<th>Cathedral/church</th>
<th>Mainly gullies/gargoyles</th>
<th>Mainly downpipes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Cologne</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Notre Dame Paris</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chartres</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Denis</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rouen</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>Bayeux</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Etienne (Caen)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Pierre (Caen)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>England</td>
<td>Salisbury</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canterbury</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Westminster Abbey</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td>Lincoln</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>York</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>St. Albans</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Details of the present water discharge systems at Lincoln cathedral (left) and Westminster Abbey (right). Both cathedrals have joint discharge systems. Note the use of chains to control overflow at Westminster Abbey
General design features of the water discharge systems at Nidaros Cathedral

At Nidaros Cathedral there are several water discharge systems, but all have in common that they are mainly based on downpipes and were designed in the 19th century or in the first half of the 20th century, as the restoration/reconstruction of the various parts of the cathedral proceeded.

Recent investigations of thousands of medieval stone fragments from the cathedral have not given any indication of the design of the medieval water discharge systems (Øystein Ekroll, pers. comm.). Thus, it is not really known whether the cathedral had parapets/parapet gutters in the Middle Ages, neither if gullies and gargoyles were in extensive use.

However, it is known that the water discharge system was subject of some discussion before and under the restoration. For example, in his 1851-reconstruction plan for the cathedral (which was never executed), architect Heinrich Ernst Schirmer did not include parapets/parapet gutters. Based on written sources, Trygve Lysaker (1973:305) notes that:

*Schirmer was familiar with the idea of adding parapets. However, even if it were possible to prove that the cathedral had parapets in the Middle Ages, he advised against building new ones. He believed that they would become almost impossible to maintain because of exposure to ice and snow. (Authors’ translation)*

The issue was also brought up during the erection of the west towers in the late 1940s. Critics maintained that architect Helge Thii’s design, which included flat roofs, would be a problem in the Trondheim climate with its rapid temperature changes (Fischer 1969:146).

Whenever possible, the cathedral was nevertheless reconstructed using parapets/parapet gutters, as well as flat roofs on top of the west towers. In principle, the design of the roofs can be divided in three categories:

1. Copper covered cast iron roofs with parapets/parapet gutters on top of the clerestory/aisle wallheads (chancel, nave, and central tower).
2. Flat roofs covered by cement/asphalt and surrounded by parapets (west towers).
3. Copper (or lead) covered timber- and cast iron roofs with stone capped gables and towers/pinnacles (octagon, transept, and chapter house).

Below, only the first category will be described. The second category concerns only a small part of the cathedral, and the third category concerns romaneseque and early gothic building parts, which are all equipped with copper eaves gutters and copper downpipes with dimensions from 50 to 100 mm (diameter). The eaves gutters and downpipes are usually underdimensioned (see later) and together with other architectural design features, as well as poor maintenance, this has given a lot of weathering and conservation problems to stonework below (see Storemyr 1997). However, the systems as such can be easily repaired and eventually altered, as the architectural design at these building parts is relatively simple.

The water discharge system at the chancel

The water discharge system at the reconstructed "neogothic" chancel, which was finished in 1890, is based on a combination of downpipes and gullies from the parapet gutters. From the main roof, water is collected in a copper gutter just above the clerestory parapet gutter and discharged via copper downpipes at each end. The downpipes end either on the ground or in the aisle parapet gutter. In this way the clerestory parapet gutter receives only little water,
which is discharged by stone gullies at each bay, just above the flying buttresses. At the south side, water flowing to the aisle parapet gutter is discharged by copper downpipes, while at the north side downpipes have been omitted, and the water is instead discharged by copper gullies. The aisle parapet gutters are not running freely along the whole chancel; they are "sectioned" since there are no passages within the buttresses/flying buttresses.

Although the copper gutters and downpipes are underdimensioned, sometimes rather ill constructed and very poorly maintained; the system as such is quite well designed. The main problem at present is related to the fact that water and ice forming from the stone gullies hit the flying buttresses, which are not designed for receiving water and ice. Consequently, at the south side they are in very bad repair. At the north side all flying buttresses were repaired 5-10 years ago, but since the design was not altered, they are beginning to show the same damages as they had before the intervention. Adding that there are probably structural problems in the chancel (ibid., Ekroll & Storemyr 1998), it is clear that either the water discharge system (the stone gullies) or the design of the buttresses have to be changed.

Over the last 100 years numerous water leaks have been recorded from the parapet gutters at the chancel, resulting in strong weathering of exterior and interior stonework, especially on the south side where the temperature changes are rapid and extreme. The leaks are probably not so much connected to the design of the water discharge system, as they are to poor maintenance and, more importantly, to the lack of high-quality covering of the parapet gutters, especially on clerestory level where they are covered only by a mortar/asphalt mixture.
(from 1950). After the aisle parapet gutters were covered with copper plates in the 1980s, the frequency of leaks has been drastically reduced here (Storemyr 1997).

It should be added that after the indoor heating of the cathedral became more and more intense in the course of the 20th century (today some 18-20ºC in the cold season), older masons report that the problem with leaks became successively worse. This can be explained by heat transfer resulting in more freeze-thaw cycles in the parapet gutters. It shows that a generally lower temperature in the cathedral would have a positive effect with regard to water leaks.

The water discharge system at the nave and the central tower

At the reconstructed "neogothic" nave, which was completed in 1930, the problem with leaks is of a similar nature as at the chancel (ibid.). However, the water discharge system is somewhat different. Except for one stone gully at each of the clerestory parapet gutters (north and south side), the system is entirely based on copper downpipes (and eaves gutters at the main roof, as at the chancel). It is designed as a joint system, implying that water from above is collected in the aisle parapet gutters.

The roofs of the nave are not the only ones contributing water to the aisle parapet gutters. From the central tower water is discharged via stone gullies to the nave roofs. Also water from the west towers and west front parapet is discharged via the nave. This means that the load on the aisle parapet gutters, which run freely along the whole nave, is very large, especially since there are only two (underdimensioned) downpipes at each side (N & S) taking the water to the ground. It seems to be obvious that this system has to be redesigned; the simplest solution is to introduce a separate discharge system.
The central tower is the only part of the cathedral where water is discharged by stone gullies only. There are 12 large gullies in action during rainfall and it seems that this is sufficient in order to keep water off the parapet gutter surrounding the base of the spire. Probably due to the fact that the parapet gutter is covered by a mixture of asphalt and mortar only, the masonry below is rather damaged by leaks (ibid.). It seems, on the other hand, that the discharged water is not doing extensive direct damage to stonework and stained glass windows below.

It should be mentioned that since the reconstruction of each part of the cathedral was successively finished in the 19th and 20th centuries, no attempt at fundamentally altering the water discharge systems has been undertaken. A few particular interventions have been made, though. In the 1960s, for example, electrical heating cables were installed in many gutters and downpipes in order to melt snow and ice in the wintertime. This attempt was very unsuccessful since ice formed at a higher rate afterwards - probably because of poor design and too little heat. After the cables were put out of use, attempts at melting snow and ice have been done by de-icing salts (calcium chloride). This practice has recently been banned because it may be very damaging if the salt is brought into contact with already extremely salt laden stonework (ibid.).
Modeling of rain water discharge and capacity of gutters and downpipes

Since it appears to be obvious that parts of the water discharge system are underdimensioned, a comprehensive study of its capacity has been undertaken by observation and modelling. The study also included drawing up a new roof plan (in AutoCAD), suggestions for improving the discharge system, as well as calculating new capacities and dimensions for gutters and downpipes. The study is reported in Jacobsen et. al. (1999) and Jacobsen (2000).

Calculation of the load (maximum discharge) on each gutter, downpipe and gully, the capacity of the existing system and the calculations for new dimensions of gutters, downpipes and gullies were undertaken using spread sheets (Microsoft Excel). A model was worked out, in which the cathedral was divided in 60 roofs and 30 walls. The location of all existing

Figure 11: From the central tower of Nidaros cathedral water is discharged via gullies only

Figure 12: Simplified roof plan of Nidaros cathedral. Areas in different graytones roughly represent from where water is drained into gutters, downpipes and gullies. Numbers indicate how many downpipes or gullies each drainage area is equipped with.
eaves gutters, parapet gutters, downpipes and gullies, as well as their dimensions, were registered and used in the model. The preconditions on which the calculations were based can be summarised as follows:

**Point rainfall intensity:** The annual average precipitation in Trondheim is a moderate 900-1000 mm (Storemyr 1997), and the point rainfall intensity, which has to be used for calculating discharge capacities, is rather low compared to more southern countries (Feilden 1982). Data from The Norwegian Meteorological Institute (DNMI) show that there is a 1% chance annually for a rainfall intensity of 2 mm/min over a period of 2.5 minutes in Trondheim. The Norwegian Building Research Institute (NBI) recommends that discharge capacities should be based on 0.78 mm/min in most "normal" cases. Feilden (1982) recommends 0.6 mm/min multiplied by a safety factor of 2. Given the complex geometry of the cathedral and the historical values at stake, a value of 2.0 mm/min was chosen for the calculations in this case.

**Wind and driven rain:** Although there are relatively few heavy storms in Trondheim each year, rain is mostly precipitated when there is westerly wind. This means that driven rain has to be considered in the calculations, because it will drastically increase the amount of precipitation that falls on steep roofs and vertical walls. Based on Hoppestad (1955) it appears that driven rain from westerly directions on average fell with an angle of 30° (0 is horizontally) in March 1953. Due to the fact that point rainfall behaves differently at the cathedral (turbulence etc.), angles between 40° and 60° were chosen in this case (depending on roof and wall orientation). In this way the discharge on average increases by 250% in comparison to "vertical rain".

**Worst case precipitation situation:** A "worst case scenario" for the amount of water that each downpipe (and gully) has to transport was worked out on the basis of defining from where the discharge water comes (area) and selecting nine different precipitation situations (precipitation of 2.0 mm/min, various wind directions and precipitation angles). The worst case precipitation situation, or the situation in which each downpipe has to transport most water, was chosen for the calculations of capacity.

**Capacity of eaves gutters and downpipes:** The theoretical capacity of eaves gutters and downpipes depends on several factors, for instance friction and the form of the "entrance" to the downpipe. Large and rounded "entrances" without grating, which is not so subjected to blocking by leaves and rubbish, have been presupposed in this case (which is in contrast to the present situation, in which small "entrances" and gratings can mostly be found). In the table below, formulas for diameter of eaves gutters and downpipes have been calculated on the basis of given capacity values from Feilden (1982) and NBI (Norwegian Building Research Institute)

On the basis of the above mentioned preconditions, calculations show that the capacity of the present water discharge system on average needs to be increased by 2-3 times in order to cope with worst case precipitation situations. It is of course clear that worst case situations are extremely rare, but the calculations nevertheless give an indication of the underdimensioned present system. At present, a worst case situation may happen, say, every hundred years, but this might not be the case in the future. If the supposed global warming continues, which
appears to increase precipitation and point rainfall intensity in Norway, worst case situations might happen more often.

Table 2: Capacity and dimensions of gutters and downpipes

<table>
<thead>
<tr>
<th>Diameter (d) (mm)</th>
<th>Capacity (Q) (Feilden 1982) (l/s)</th>
<th>Capacity (Q) (NBI) (l/s)</th>
<th>Diameter (d) (mm)</th>
<th>Capacity (Q) (Feilden 1982) (l/s)</th>
<th>Capacity (Q) (NBI) (l/s)</th>
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<tr>
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<td>1,43</td>
<td>90</td>
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</tr>
<tr>
<td>150</td>
<td>2,3</td>
<td>2,21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ d = 106 \cdot Q^{0,4} \]
\( D=\text{diameter (mm)}, \ Q=\text{capacity (l/s)} \)

\[ d = 53 \cdot Q^{0,4} \]
\( D=\text{diameter (mm)}, \ Q=\text{capacity (l/s)} \)

Thus, as a safety precaution, in this case it is recommended that the capacity of the present system on average should be increased by 2-3 times. In some cases this means that the dimension of downpipes has to be increased by 6 times.

For the re-dimensioned system it is presupposed that stone and copper gullies should work as they do at most building parts today: as safety precautions against overflow. At places where they work as the main or only discharge system today (central tower and north aisle of the chancel), it has been presupposed that their dimensions should be similar to downpipes.

Alternative solutions for improving the water discharge system at the chancel

In order to show how the calculations might affect the water discharge system in practice, the south side of the chancel will be taken as an example. This example not only considers rainwater discharge, but also how snow and ice might affect the decisions to be taken. The south side of the chancel has been selected because of its very poor condition due to leaks, and because the climatic situation is much more difficult here than on the north side (extreme and rapid temperature changes).

The following alternatives for altering the water discharge system have been considered:

1. A system working more or less like today. This system should be based on the idea that water from the main roofs collects in eaves gutters (instead of entering the parapet gutter) and is discharged by downpipes reaching to the ground (separate system). Thus, the stone gullies would only discharge water collecting in the parapet gutter itself and simultaneously work as a precaution against flooding. From the aisle parapet gutter water would have to be discharged via downpipes at each bay, and stone or copper gullies inserted as a precaution against flooding.

2. Completely open system based on parapet gutters and gullies only. This would have to be a joint system, since it is not possible to let water discharge via gargoyles and gullies to
the ground from the flying buttresses. The main drawback of this alternative is that discharge water cannot be controlled easily (risk of damages to stonework below and stained glass windows, as well as difficulties with draining the water on the ground). Moreover, the size and frequency of icicles forming from the aisle gullies would be larger than in alternative 1. This might represent a hazard for passers-by and for stonework and windows below.

3. Completely closed systems based on gutters and downpipes only. This could either be a joint or a separate system, but a separate system would be preferable since it would reduce the load on the aisle parapet gutters. In order to obtain a reasonable safety margin with regard to floods, downpipes would probably have to be installed at each or every second bay at clerestory level. The main drawback of this system is that these downpipes would quite drastically alter the architectural design of the chancel. Moreover, it is difficult to find a good solution for the downpipes in the transition zone between the wall and the flying buttresses. The buttresses might also have to be equipped with watercourses. For the aisle there is no real problems, but two downpipes at each bay might have to be installed (since the aisle parapet gutter is sectioned).

4. Complete alteration of the roofs. This would for instance imply that the roofs were extended over the parapets and equipped with installations against major snowslides. The drawbacks of such a solution are obvious; it would completely alter the architectural design of the chancel and snowslides would be impossible to control properly. On the other hand such a solution would make a definitive end to water leaks from parapets.

5. Covering of parapets by provisional roofs in the wintertime, in order to avoid freeze-thaw in the parapet gutters and subsequent water leaks. The drawbacks are of a similar nature as described above.

All the alternatives would have to include repairing the flying buttresses, cover them with metal and eventually make them able to receive water in new watercourses. Moreover, the parapet gutters would have to be thoroughly repaired and much better insulated than today (except for alternative 4). The covering system would have to be considered very carefully, but properly executed, thick lead plates welded together is perhaps the best solution. It should also be considered whether electrical heating cables in downpipes could help improve the situation in the wintertime. Also very local heating of gullies could be considered in order to avoid large icicles.
In all cases, the rain water discharge capacity should be increased when compared to the present situation. If selecting alternative 1, and according to the calculations described in the previous section, the capacity of downpipes would have to be increased 150-200%.

Historical records of water leaks from the parapet gutters show that most, if not all, leaks happen in the winter time (Storemyr 1997). This means that leaks are usually not caused by overflow situations when it rains, but by the collection of snow in the parapets, freezing and thawing and the fact that the parapet gutters are poorly insulated. Moreover, it seems that the worst leaks have happened from places where structural problems have contributed to crack formation in or close to the parapet gutters (cf. ibid., Ekroll & Storemyr 1998).

Taking these considerations into account, alteration of the main roof or covering the parapet gutters by provisional roofs in the wintertime seems like tempting solutions. However, these solutions have disadvantages as shown above. Since the other solutions also have serious disadvantages, we recommend alternative 1 as the best. This alternative demands intensive maintenance, which must be improved drastically. Today several downpipes are not even connected to the eaves gutters; they have been destroyed and not repaired.

**Concluding remarks**

In this paper it has been shown that in order to cope with heavy rainfall, the capacity of the water discharge system at Nidaros cathedral should be increased some 2-300%. However, in order to avoid the majority of water leaks, proper covering of parapet gutters, effective disposal of snow and other maintenance actions seem to be of greater importance. This is because the overwhelming number of leaks takes place in the cold season.

It is tempting to recommend extending the roofs over the parapet gutters in order to avoid freeze-thaw problems. This is, however, going to drastically alter the architecture and also allow snowslides to affect stonework below. Moreover, when recommending a repair programme rather than a reconstruction programme, we also consider that good conservation practice is to alter as little as possible and undertake interventions which can be corrected in the future. In this respect it should also be noted - it

*Figure 16: To be avoided in the future: Flooding of the aisle parapet gutter at the nave*
cannot be underlined strong enough - that regular maintenance and maintenance programmes are of utmost importance.

In the project a spread sheet model of rainwater disposal at the cathedral has been developed. This model has been of great help for calculating gutter and downpipe capacities. With some alterations and improvements, the model can also be used for designing rainwater discharge systems at other buildings.

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