HISTORICAL-MACROSEISMIC STUDY OF THE TOWN CHURCH IN WITTSTOCK, NORTHERN GERMANY

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Abstract

The St. Marienkirche in Wittstock, a town in Northern Germany, is known to have significant damages in the walls. According to historical sources, these damages were supposed to be caused by an earthquake in the year 1409. However, Northern Germany is a region of low seismicity where damaging earthquakes are very rare, and there is debate on the causes for the damages in the church. We investigated and interpreted the damages in the church with the objective to clarify their seismic or non-seismic origin.

Our investigation reveals a few tens of individual damages at the building. They can be grouped in 5 types of damage patterns: long fissures cutting whole walls, through-going joints cutting few adjacent bricks, fissures cutting windowsills, window arches, and vaults; rotation of wall fragments; bricks package partially pushed out of walls; different preservation's degree of walls with different trends; features of later repairs.

We conclude that at least part of the observed damages are probably caused by an earthquake. The church is situated on flat lowland, built on loose alluvial deposits with high level of the underground waters. Hence, site-effects are expected to have affected the patterns of the seismic damage.

1. Introduction

The St. Marienkirche in Wittstock, a town in Northern Germany (Wittstock town church - WTC) is known to have significant damages in the walls. According to historical sources, these damages were supposed to be caused by an earthquake in the year 1409. However, Northern Germany, the German lowlands, is a region of low seismicity where damaging earthquakes are very rare, and there is debate on the causes for the damages in the church (Grünthal and Meier 1995). We investigated and interpreted the damages in the church with the objective to clarify their seismic or non-seismic origin.
The St. Marienkirche today has the following main dimensions: length 64 m; width 23 m; height of the tower 65 m; thickness of the walls in the upper part of the tower approx. 2 m. The oldest part of the church including the lower part of the tower was constructed in the first half of the XIII century. Before 1698 the tower had a height of approximately 122 m. Details of the construction history are described in Büttner (1907) and Zellmer (1998).

2. Investigation in Wittstock

The investigations in Wittstock were conducted in 2001 (Kaiser and Korjenkov, 2002; Korjenkov and Kaiser, 2002a, b). The special historical-macroseismic study reveals damages in the building discussed in the following. Many of them have not been described before. They can be grouped in 5 types of damage patterns: a) long fissures cutting whole walls of the church, through-going joints cutting few adjacent bricks, fissures cutting windowsills, window arches, and vaults; b) rotation of wall fragments; c) bricks partially pushed out of walls; d) different preservation's degree of walls with different trends; e) features of later repairs.

1.1. Fissures in the walls of Wittstock church

2.1.1.Fissures' formation

Many old buildings, even with high quality of building design and work, begin to crack with time. This cracking is caused by accumulation of static ("dead") loading, "growing old" of building materials, weathering with time. Fissuring can be also produced by effects of military actions (like ramming or bombing) or by dynamic influences, for example, by ground motions caused by an earthquake(s).

Generally, different sorts of fissures can be divided into two main groups by their configuration: oblique and sub vertical (Fig. 1). The oblique fissures usually use a space between bricks (stones) for their propagation, as "easier way" to break the wall. Such fissures can be produced by both agents: static and dynamic ones (Stiros, 1996).

a

b

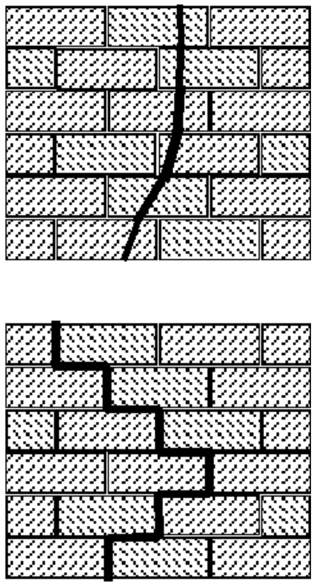


Fig. 1. Different types of fissures in the damaged walls: a - through-going joints, supposing their seismic origin, b - orthogonal cracks, which can be produced by the static loading or seismic oscillations.

1.1.2. Through-going joints cutting few adjacent bricks

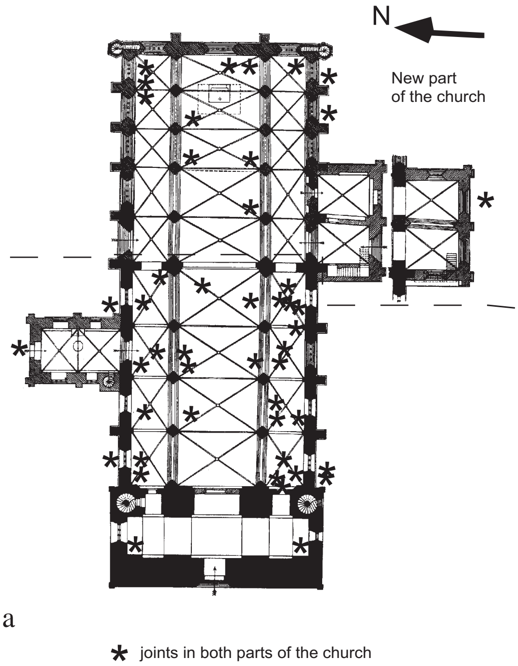
Joints crossing a few adjacent stones is one of the strong evidences of seismic origin of the deformations (Stiros, 1996). Unlike oblique cracks, the through-going joints cutting few adjacent bricks can be produced only by dynamic influence (Korjenkov and Mazor, 1999a,b). The reason that such through-going joints are formed by strong dynamic loading, e.g. as a result of the earthquakes of significant intensity is understandable in light of the high energy necessary to overcome the stress shadows of free surfaces at the stone margins (i.e., the free space between adjacent bricks or stones).

The criterion of through-going joints cannot be overestimated in determination of the seismic origin of the damage and in assessing of the intensity of historical earthquakes. Long through-going joints in bricks were observed in the Wittstock church tower. Their lengths can reach tens of meters, like a long fissure visible in the external side of the southern wall of WTC tower. Mainly joints in the WTC have lengths of several meters with width of opening up to a few centimeters.

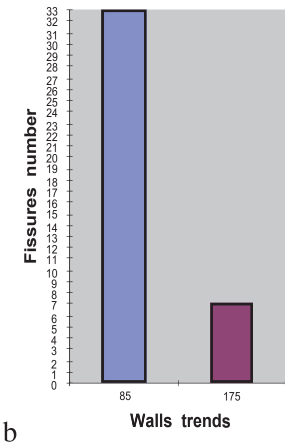
Side by side with wide open sub vertical through-going joints, one can observe in the wall plaster the narrow tree-like and thread-like fissures of unclear genesis. They are located near the windows and there are many of them also in the vaults of the church. It is not clear how deep these fissures are penetrating into the wall. These fissures are located close to each other and have different trend in one building element. Their present form could suggest their slow propagation because of the static loading with time, although their initial occurrence can be caused by an earthquake. Their possible seismic origin is suggested by their occurrence in the upper part of the building, where loading is minimal as compared with the lower part of the church.

We mapped the fissures, which can be seen in the walls, arches and vaults of the Wittstock church. It is necessary to mention, that internal parts of the WTC walls were recently repaired and the part of the existing fissures are either not observable any more or badly visible under the plaster, so it is difficult to estimate the degree of their development and origin. In the old part of WTC 40 cases of fissures have been mapped (Fig. 2a), almost all of them (82%) occurred in the wall with sub latitudinal (80°-85°) trend (Fig. 2b). In the "new" part of the church the walls with both trends have almost the same number of the fissures (Fig. 2c), although the walls trending 175°-180° have a little more fissures (60%). This means that different parts of the church have different history of external influences.

It is important to note, that the walls of the younger part of the church have through-going joints also. They are located mainly in the eastern wall of the church. This fact can be (1) an evidence of another significant earthquake which happened after completion of the new part of the church or (2) a consequence of permanent vibrations arising from trucks and cars passing near the eastern wall along the street located in 1 m distance east of that wall.



a



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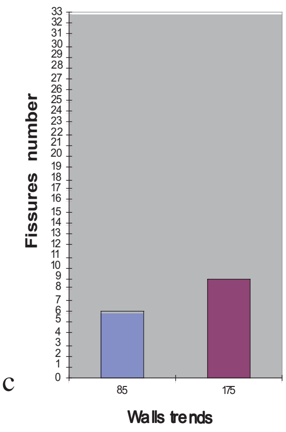

c

Fig. 2. Fissures' occurrence in the WTC:
(a) - An architectural plan of the church (after Büttner, 1907), "stars" - *** show the location of fissures;
(b) - fissures occurrence in the old part of the WTC;
(c) - fissures occurrence in the younger part of the church.

2.2. Rotation of fragments of walls

Rotations of single bricks, stones or wall fragments around vertical axis are rare types of damage, which are observed in historical monuments. To cause such rotations it is necessary to involve significant dynamic forces, like ramming or explosions. However, systematic pattern of rotations in the walls with the same trend, found in one building or in a group of buildings of the same age, can be produced only by significant ground oscillations.

Systematic rotation of wall fragments or entire walls around a vertical axis indicate strong seismic movements at some angle to the wall trend. The theoretical background of this phenomenon has been discussed in detail by Korjenkov and Mazor (1999b, c). Example of case of rotations in the WTC is given in Fig 3. Widths of rotated brick packages are up to 1 m, they are several meters high. Thickness of the walls in this part of the building is 2 m. Two clockwise rotations were observed at the tower of WTC on walls trending 80°-85°. Thus, the seismic motions were oblique to those walls along the NNW-ESE axis (Fig. 3).

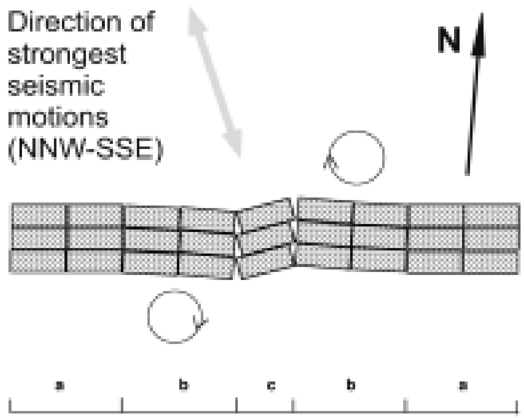

Fig. 3. Rotations in Wittstock church's tower: a model explaining observed rotation pattern. a - undeformed wall, b - parts of the wall underwent clockwise rotations, c - transitional zone of drag (counterclockwise) rotation.

2.3. Bricks partially pushed out of walls

Displacement of the building elements is a well-known phenomenon of earthquake deformation in ancient buildings and were used for the determination of the seismic motions' directions as wall tilt or collapse (Korjenkov and Mazor, 1999b, c). The only process that could cause such shifting is an earthquake - no other mechanism is known.

The southern wall of the church shows not only rotation of the wall fragment, but also bricks that were partially pushed out of the wall. The bricks are pulled out westward to the distance up to 10 cm. The pushed bricks observed in the Wittstock church tower provide by themselves a criterion of seismic damage.

2.4. Differen degree of preservation of walls with different trend

Preservation of walls of a preferred direction testifies that destruction was by an earthquake. This statement is followed from the previous paragraphs, that the wall located perpendicular to the direction of the seismic motions would have a maximum freedom for oscillation, which would lead to maximum damage, if compared with a wall located parallel to the direction of the seismic movements (Korjenkov and Mazor, 1999a, b; Mazor and Korjenkov, 2001). So the strong seismic motions were parallel to the preserved wall trend.
In upper part of WTC tower one can observe that walls with different trends have different degree of the damage. This statement can be clearly demonstrated by different preservation of decorative brick arches attached to the walls (Fig. 4): arches attached to the sub longitudinal walls (trend 170°-175°) preserved rather well (Fig. 4a), however arches on perpendicular walls preserved only partly (Fig. 4b). It is important to mention here, that sub latitudinal walls have also maximum occurrence of the fissures and rotations, so the fact that arches here had maximum destruction is an additional evidence for the seismic origin of damage.

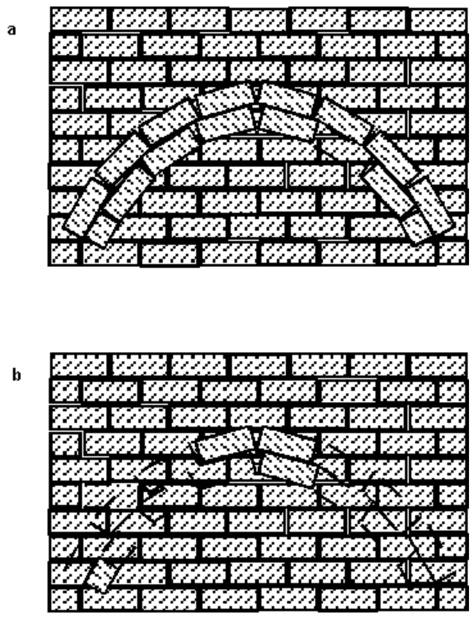

Fig. 4. Different degree of damage of attached arches in the walls with different trends in upper part of the Wittstock church's tower. a - walls trending 170°-175°, b - walls trending 80°-85°.

2.5. Features of later repairs

Repairs in houses of certain age can serve as supportive evidence of seismic origin of deformation (Stiros, 1996). Those repairs and later rebuilding are usually of low quality than the original structures.

Northern wall shows numerous features of later repairs at the WTC tower. First, the former window is blocked by bricks. This blockage was not occasional: the wall above the window was severely destroyed (there are fissures above the window arch). Part of the wall east of the window was collapsed, and now there is a new brick masonry there. People tried to repair cracks, so one can observe traces of plaster above the window.

These features of later repairs can not be occasional. At the beginning, the wall (with trend 80°-85°) was severely damaged: parts of the wall was rotated, part of it collapsed, the wall has numerous fissures, and attached arches are damaged worst. Later, people tried to repair this damage.

3. Discussion

Wittstock town is located in Northern Germany, a region with low seismicity. According to the earthquake catalog of Germany (Leydecker, 2003) the maximum macroseismic intensity observed in this region was I = 5-6. However, the high degree of the seismic damage observed in the Wittstock town church can be explained by a number of unfavorable factors:

- First, the church was built on the Holocene loose alluvial deposits of the river Dosse. There are silts and clays left by the river. During an earthquake such poor ground conditions can lead to a subsidence of the ground and to a local increase of seismic damage up to one grade of EMS-98 scale.
- Second, because the river Dosse flows nearby, the ground water are inclining to its level, so the level of the ground water is high in the region of WTC. High level of ground water at WTC has been documented by K. Zellmer (personal communication 2001). Near the parking lot, which is close to the Wittstock church, we have observed even swampy grounds indicating that ground waters reach the surface. High level of the ground water is also an unfa-

vorable factor for buildings: it also can increase the seismic damage up to one grade of ESM-98 scale.

- Third, maximum damage was observed in the upper part of the church tower. This fact can be explained by the “sky-scraper” effect that result from higher degree of oscillations of the higher part of the structure. Such effect was observed during recent Suusamyr earthquake (1992, Ms =7.3) in Kyrghyzstan. In Bishkek - capital of Kyrghyzstan located 100 km from the earthquake epicenter - general estimation of seismic intensity was I = 5, however on the 16th floor of one of tallest buildings in the city, it was observed the local seismic effect of I = 7.

All written above do not testify about the possibility that strong earthquakes occurred in northern Germany, but about the fact that even moderate seismic intensities can produce significant damage in tall buildings built on unconsolidated grounds with high level of the underground waters. In order to quantify the site-effects on the patterns of the seismic damage, a detailed knowledge of the geotechnical and hydrogeological ground conditions at the church will be necessary.

Systematic pattern of deformations in the walls of the same trend shows the influence of a horizontal component of the seismic movements (Korjenkov and Mazor, 1999b, c). Walls, which are perpendicular to the direction of the seismic motions, have maximum damage because of maximum freedom of oscillation (Fig. 5).

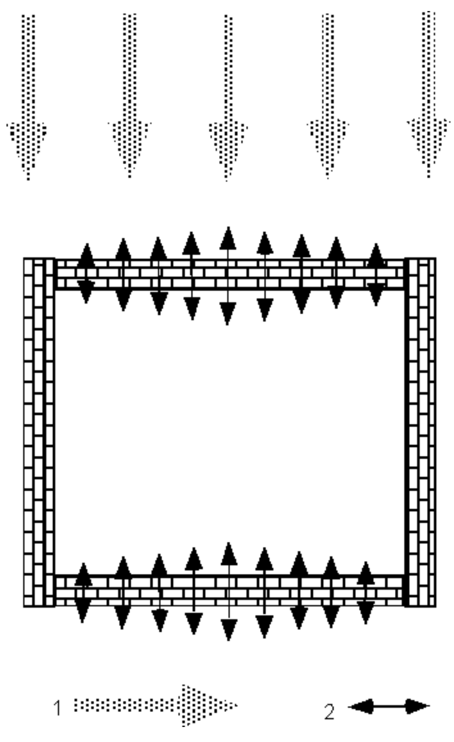

Fig. 5. Different freedom of oscillations (2) for walls with different trends, exposed to seismic movements (1).

Maximum damage occurrence in the walls of sub latitudinal trend suggests that the strongest seismic movements were roughly perpendicular to the wall of this trend, however the existence of rotated parts of the walls means that strong seismic motions occurred at some angle to the walls of that trend (Fig. 6). So, the most probable direction of the strong seismic movements is along NNW-SSE axis.

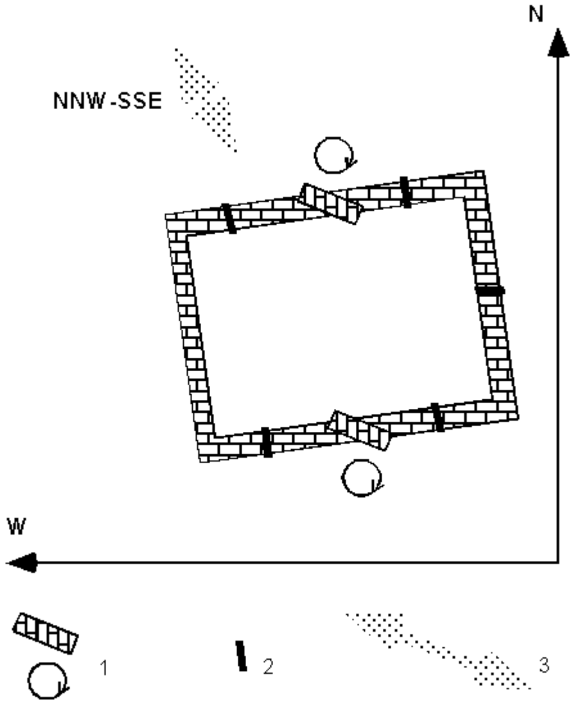

Fig. 6 A model explaining the observed damage patterns in upper part of the Wittstock church. 1 - clockwise rotations, 2 - through-going joints, 3 - axis of the seismic movements

The encountered features of seismic damage in the Wittstock town's church could be cased by an earthquake(s) listed in the catalog of Leydecker (2003) or an unknown earthquake.
A quick look on the Wittstock town's wall and bishop house in Wittstock, which have roughly the same age as the WTC, revealed some damage features, which possibly can be attributed to seismic activity. Additional study of these features is needed.
All observations described above suggests that additional investigations are necessary to clarify the occurrence, the strength and the location of significant earthquakes in the region.

4. Conclusions

1. A few tens of individual observations, made at WTC reveal 5 types of damage patterns reported above. These damages, or part of these damages, are most probably caused by an earthquake.
2. Maximum occurrence of the damage features was observed in the walls trending E-W. Systematic pattern of the deformations in the walls of the same trend shows the existence of a horizontal component of the seismic movements.
3. Rotations of the wall fragments are observed at the WTC to be clockwise at walls trending E-W (80°-85°). Thus, the strong seismic movements probably occurred oblique to these wall trends - along NNW-SSE axis.
4. Maximum degree of damage observed in the upper part of the church can be an evidence of the "sky-scraper effect", known during recent earthquakes.
5. Wittstock town church is situated on flat lowland, built on loose alluvial deposits with high level of the underground waters. Hence, site-effects are expected to have affected the patterns of the seismic damage.

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