ADVANCED MASTERS IN STRUCTURAL ANALYSIS
OF MONUMENTS AND HISTORICAL CONSTRUCTIONS

Master's Thesis

SHUNLI YOU

Structural Survey of Historical Building Strahovská FARA in Pohořelec

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MASTER'S THESIS PROPOSAL

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Framework content: This thesis focusses on the structural survey of historical building Strahovská FARA in Pohořelec Prague. Thesis includes 9 main sections, which are Introduction and Methodology of building, Location and Historicla Backgorund of Monastery and City Prague, Historical Survey of Strahovská FARA, Site Survey, Failures of Structures and Material Deterioration,Static Analysis, Intervention Proposal and Maintenance Plan.

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Eva Burgetová
Master's thesis supervisor

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Head of department

Date of Master's thesis proposal take over: 3rd July 2017

Student

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DECLARATION

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Supervisor(s): Professor Eva Burgetová

Year: 2017

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

I hereby declare that the MSc Consortium responsible for the Advanced Masters in Structural Analysis of Monuments and Historical Constructions is allowed to store and make available electronically the present MSc Dissertation.

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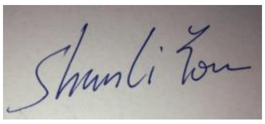
_____  (ShunLi You)_________

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This thesis on structural surveying of the historical building on Strahovská FARA in Pohořelec has been compiled after referring to a certain number of published books and journals, making site visits and finally in consulation with my supervisor Professor Eva Burgetová. This thesis would not have been possible or most probably would not have been completed on time with this quality, without the extensive efforts of professor Eva Burgetová as she supervised this work.

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ABSTRACT

The aim of this work is to carry out the structural survey and remedial proposal of historical building Strahovská FARA in Pohořelec located in a significant historical location next to the Prague Castle. The building Strahovská FARA was constructed in Gothic style at 14^{th} century and rebuilt in Baroque style at 18^{th} century. Nowadays, the building belongs to the Strahov monastery in Prague. It presents not only the architectural importance but also the cultural and historical meaning of Prague. In order to preserve this building, all aspects including site, its geology, causes of failures and deterioration, static analysis and intervention and maintenance proposal have been carried out. Non-destructive and minor-destructive tests such as moisture content determination, chemical analysis, spectrophotometric test and mechanical characteristics determination have been performed, in order to qualitatively investigate the building. Based on the previous material characteristics determined by laboratory tests, the numerical structural model has been done. After investigation and all analysis could be stated, the building Strahovská FARA has no static problem, main causes of decay are dampness and settlement. Therefore, three necessary interventions including crack repairs, column replacement on main facade and interventions of moisture problem have been carried out. The goal of intervention proposal is to recover its initial structural and aesthetic integrity and keep its authenticity of historical building. All suggested interventions in this work follows the definition of "Conservation" given by ICOMOS with minimum and reversible interventions.

ABSTRACT

Cílem diplomové práce je provedení a vyhodnocení stavebně historického a stavebně technického průzkumu budovy Strahovské fary na Pohořelci v Praze a koncepční návrh rekonstrukce. Objekt se nachází v historicky významné lokalitě nedaleko Pražského hradu.

Strahovská fara byla postavena ve 14. století v gotickém slohu, později v 18. století barokně přestavěna. Dnes fara patří Strahovskému klášteru – jednomu z nejvýznamnějších v České republice. Budova představuje nejen architektonické hodnotu, ale také kulturně historickou.

Pro zachování této historické budovy byly vzaty v úvahu všechny aspekty, které ovlivňují její funkčnost a spolehlivost, tj. lokalita včetně geologické situace, příčiny poruch konstrukcí a degradace stavebního materiálu. Byly použity metody NDT a MDT pro stanovení obsahu vlhkosti a mechanických vlastností stavebního materiálu, v rámci chemické analýzy obsahu solí byl proveden spektrofotometrický test. Současně byla řešena statická analýza konstrukce. Byly navrženy opravy vybraných konstrukcí a plán údržby.

Na základě zjištěných a laboratorně ověřených dat byla provedena numerická analýza a výpočetní model konstrukce. Pro vyhodnocení průzkumů a všech analýz bylo konstatováno, že statické poruchy nejsou závažné a hlavní příčinou většiny poruch je vlhkost, případně pohyb podloží. Byly proto navrženy tři hlavní zásahy do konstrukce: oprava trhlin, výměna sloupů arkády na uliční fasádě a ochrana objektu proti vlhkosti. Cílem opatření je zachování integrity a historické autenticity objektu při dodržení zásad daných směrnicemi ICOMOS, tj. především minimalizovat zásahy do konstrukce a navrhovat reversibilní řešení oprav.

ABSTRACT

此学术论文的学术目标是针对位于布拉 Pohořelec 区的的一个重要的历史建筑 Strahovská FARA 的结构检测与修复方案。Strahovská FARA 建造于 14 世纪以歌德式建筑风格为主。经过一些历史与战争原因，Strahovská FARA 的某些部位受到了不同程度的损坏，并在 18 世纪重建为一个巴洛克风格的建筑。现在，此建筑直属于布拉格著名的 Strahov 修道院。这所建筑不仅展现了自身独特的建筑魅力，而且也展现了布拉格的建筑文化与部分历史。

为了更好的修复与保护此建筑，以下因素在论文中被涉及：分别是实地考察报告，地质报告，损坏程度与原因，静力结构安全分析，合理修复方案与持续性维护计划。为了更好的分析以上所提及的部分与得到一个可靠性的分析结果，无损性测试（NDT）与可修复损坏性测试(MDT)被使用，这些测试分别是材料的湿度测试，化学测试，分光光度测试与材料性工程测试。

根据以上测试的结果，静力的数据模型被创建与分析。根据数据模型，Strahovská FARA 到目前为止没有可破坏性的结构问题，但是材料的湿度与地基下陷的问题直接的影响了建筑的本身，可能在未来带来破坏性的结构安全问题。所以此论文提出了三个可行的修复方案（裂缝修复，柱子修复，材料湿度修复）。在保证建筑的自身原样性，真实性与美观性的基础上，根据 ICOMOS 的修复规定与要求，进行可持续性修复。

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1. Introduction

Historical structures are vulnerable construction, and it can stimulate our desire to know more about people and culture that created it. The concept of an historical monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of particular civilization, a significant development or an historic event [1].

The historical building Strahovská FARA located in the historical location Pohořelec next to the Prague Castle presents the cultural and historical meaning of Prague history. It is important to know the historical background of construction. For ensuring long-term functional qualification and durability of regenerated and interventions, the quality of the properties of material and condition of the structure established through diagnostic means and in-situ and laboratory investigation have been considered as preliminary researching factors. After the site survey, deterioration survey and static analysis of this historical building, it has major concern of moisture problem. Moisture problem brings static influence on the material of building Strahovská FARA, which could cause static problem in the future. In many cases, the result of a survey will influence the extent and manner in which a building is altered, repaired, and maintained, as well as how resources are used and consumed in the process [2].

Furthermore, due to the non-professional usage of addition or substitution of material or techniques, it is highly possible that the building leads to destruction and loss of the historical value. Therefore, professional restoration plays principle role in the preservation of historical building. Due to major problems of historical building Strahovská FARA in Pohořelec, the restoration and conservation of building should be considered and applied, in order to retain its antiquity and architectural authenticity. The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to study and safeguarding of the architectural heritage [1]. On the other hand, during the conservation, restoration and reparation of a historical monument should be kept a minimum and reversible level, in order to retain the significance of the historical monunment.

2. Methodology

The major purpose of this dissertation is to study the historical building Strahovská FARA in Pohořelec and analysis causes of failures and deterioration, in order to design the principle of rehabilitation methods and procedures. This thesis pays attention to point out the risk factor, limitations and efficiency of usability with regards to the requirements for the functional reliability and durability of building. By achieving the aim of dissertation, this paper uses results from geological survey (Ing. Lumir Caithaml, 2016) and includes historical survey, site survey, deterioration survey, static analysis, in-situ investigation and possible interventions with maintenance plan done by author.

At the first part of this dissertation, it mainly focuses on the detailed analysis of the technology development of historical measures. The urbanization of the city Prague, development of the Strahov Monastery and historical background of building Strahovská FARA have been analyzed.

At the second part of this dissertation, it pays attention to investigate the cause of failures, specification of degradation factors and material analysis. The deterioration survey and site survey have been analyzed. The aim of this deterioration survey is to make assessment of the historical building Strahovská FARA as a basic for a decision in principle about the type of rehabilitation, and to collect the future demands for further detailed analysis. In addition, tests have been done at the Department of Building Structure FCE CTU (Faculty Civil Engineering of Czech Technical University) in Prague. The aim of tests is to characterize the building material and determine its properties of material. The main deterioration agents and causes on the historical building Strahovská FARA have been clarified after laboratory test.

At the third part of this dissertation, it focus on the detailed survey of the historical building Strahovská FARA. The static condition has been investigated by using the numerical modelling of main façade on the building. The aim of this section is to make judgement of qualification and reliability of the structures, which the residual durability of the historical building Strahovská FARA and future restoration can be predicted.

Finally, possible interventions for deterioration and decay of the building Strahovská FARA and its maintenance plan have been proposed. All possible interventions follow the definition of "Conservation" given by ICOMOS.

"The object of conservation is to prolong the life of cultural heritage and, if possible, to clarify the artistic and historical message therein without the loss of authenticity and meaning. Conservation is a cultural, artistic, technical and craft activity based on humanistic and scientific studies and systematic research. Conservation must respect the cultural context [3].

3. Location and Historical Background of Monastery and City Prague

3.1 Location

The historical building Strahovská FARA located at the Hradčany district of Prague. Hradčany district is on the western edge which is also the former settlement of Prague. The capital city of the Czech Republic—Prague situated on the Vltava River with 31km long flowing through Prague, at 50°05''N and 14°27''E in the center of the Bohemian Basin. It is less obvious from a map of Prague city that it is built over a series of district hills. The distinctiveness of each district is a result of the four original towns of Prague, developing independently and only merging into a single political and economic entity in 1784, which were Old Town at Stare Mesto Praha 1, The New Town at Nove Mesto Praha 2, The Lesser Quarter, and the Castle District on Hradčany [4]. Those districts are most important historical areas in Prague

The historical building Strahovská FARA at the Hradčany district of Prague has short walking distance to the Strahov Monastery and is next to the Prague Castle. The building Strahovská FARA belongs to the Strahov Monastery. Specifically, the historical building Strahovská FARA located at the square Pohořelec with house number 114/22 (See Figure 1).

Figure 1: Location of Building Pohořelec (Google Map)

3.2 Historical Background of Monastery and City Prague

3.2.1 History of City Prague

Due to the river Vltava, there were numerous stream and rivulet valleys which were found and settled in the ancient times. The great location of Prague Basin provided an opportunity for people doing the business trading and exchanging cultural idea, constantly, it became an important crossroad of trade routes and culture. As the Prague Castle settled itself on the Hradčany in 9th Century by Premysl Otakar II of the Premyslid dynasty, a market settlement the Lesser Quarter (Malá Strana) was found as first district of Prague. During the eleventh century farmsteads on the east bank of the river Vltava began to merge into a mercantile center whose market square was in place by 1100, and the Old Town (Stare Mesto) was officially incorporated with its own council overseeing its affairs [4]. In the Old Town, there were walls surrounded, but only the gate of Powder Tower remains until today. After Old Town established, the third town of Hradčany was found in 1320 under the administration of the Prague Castle [5]. In 1348, the New Town (Nove Mesto) was found by the chief designer and king of Prague Charles IV.

3.2.2 History of Strahov Monastery

The idea of constructing Strahov Monastery in Hradčany district of Prague came from a Bishop, Olomouc Jindrich Zdík, after his pilgrimage to the Holy Land in 1138. However, this construction idea did not success until Premonstratesians arrived in Strahov from Old Steinfeld in the Rhineland. The following dates shows the most important events to the monastery after its construction (See Table 1). The stone Strahov Monastery and Basilica in 1182 can be shown in Figure 2.

Figure 2: Stone Strahov Monastery and Basilica [6]

Table 1: Important Events of Strahov Monastery [6]

In 1140	a wooden monastery and romanesques basilica were built
In 1182	Stone was applied to Strahov Monastery after completing the romanesques basilica
In 1258	the monastery was reconstructed after fire damage
In 1420	the monastery stopped its further development due to the plunder of Hussites
In 1586	Jan Lohelius, the Strahov abbot started to reconstruct and restore the monastery
In 1648	the abbey of monastery was sacked and plundered by Swedish army, after that, the reconstruction and restoration of monastery started. The library hall of monastery is completed
In 1679	the brewery is rebuilt in the 18th century
In 1742	the monastery was hardly damaged by the war, but the original medieval structure were rebuilt in Baroque spirit after the war.
In 1950	the Communist regime took the monastery as official building, but part of the Romanesque structure of monastery was renewed in a very careful way
After 1989	The abbey was returned to the Premonstratensians, and further developments and constructions continue.

4. Historical Survey of Building Strahovská FARA

Historical survey is to establish the historical significance of the historical building Strahovská FARA and to detect any structural alteration or events, which affect the present state of the structure.

4.1 History of Building Strahovská FARA

Due to lack of the historical material of this building, some basic historical backgrounds of the building Strahovská FARA have been investigated. The building located in Strahov parish was constructed in 14^{th} century in gothic style. This Gothic townhouse, recorded as a possession of adjacent Strahov Monastery from 1382 was rebuilt in Renaissance period (16^{th} century) and later in 18^{th} century in Baroque styles [7]. The arches and ribbed vaults supported the arcade on the main façade presents its Renaissance characteristics. The roof, existing windows and sign of Our Lady with Infant Jesus are in Baroque style.

In 1382, when "dvorni pristavba" (garden) of building Strahovská FARA under construction, part of the main building was damaged. During the Middle Age period, only basement was preserved. Around 1601, a remarkable reconstruction was carried out except arcade. The first part of the house (building 1 and arcade) was completed in 1704. In 1732, the construction of second part of house (building 2,3) was completed. However, because of war occurred in Prague city from 1741 to 1742, major part of buildings was damaged by artillery. The building was in an uninhabitable condition after the war. The building was restored in 1773 by Strahov monastery. After 1773, the building Strahovská FARA was managed, repaired and maintained by Strahov Monastery as parish house. Additionally, the building Strahovská FARA is an office and residents for priests and monastery sisters nowadays.

Based on historical documentations, the historical photo was taken in 20^{th} century, and it showed that supporting columns had effect of moisture (See Figure 3). The recent restoration occurred in 2011, all columns have been strengthened by iron frame and concrete material as layer.

Figure 3: Building Strahovská FARA in 20th Century (Strahov Monastery Provided)

4.2 Main Historical and Architectural Features of Building Strahovská FAR

4.2.1 Vaults and Arches

The historical building Strahovská FARA utilized the local stone named opuka, which is a specific typical sedimentary rock in west of Prague city. The main façade of the building Pohořelec consists of 3 Gothic vaults as Quadripartite Gothic Vault and arcade (see Figure 4).

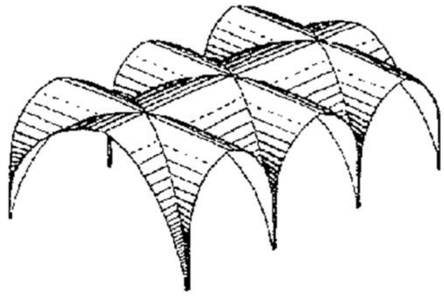


Figure 4: East Side Vault of Main Façade

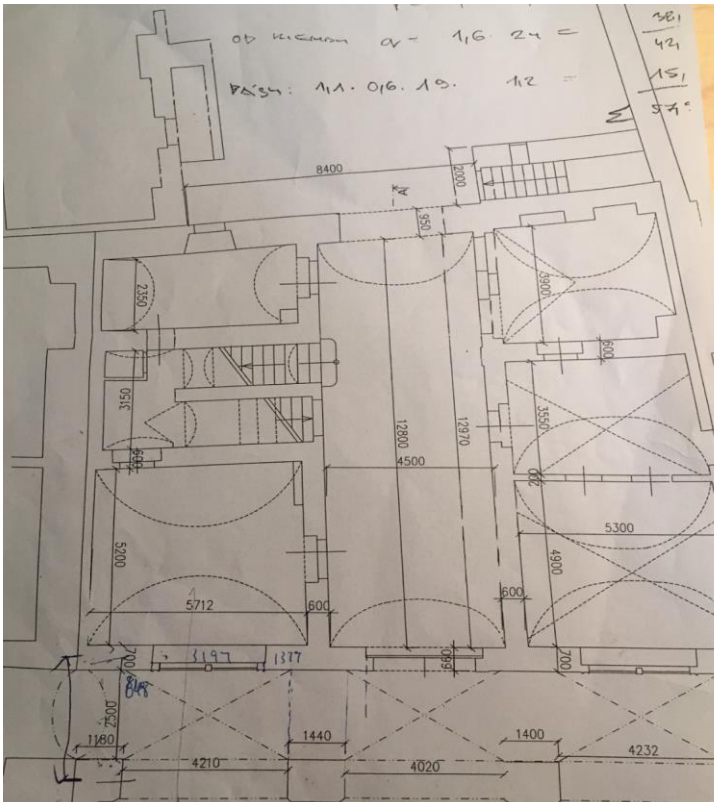
Gothic vault is an advanced technique comparing to Romanesque vault, which started to utilize in construction since 12th centuries. By the 12th century, architects realized the superiority of the groined vault compared to the barrel vault and started to add ribs, which were used to support the weight of the vault [8]. The ridges of Quadripartite Gothic Vault are held in position by equal and opposite thrusts; all the compressive forces are brought down to the "tas de charge—ribs" [3].

Arche doors are utilized at front of the main facade, and all dimensions of each arches have been shown in Figure 5. Obviously, each of the arch doors has long-spain with low raise. The hinge effect has been founded on each of the arche doors. The hinge effect is most relevant when depth of the voussoirs are deep in relation to the span [3]. In this case, arches are able to absorb deformation generally by slippering.

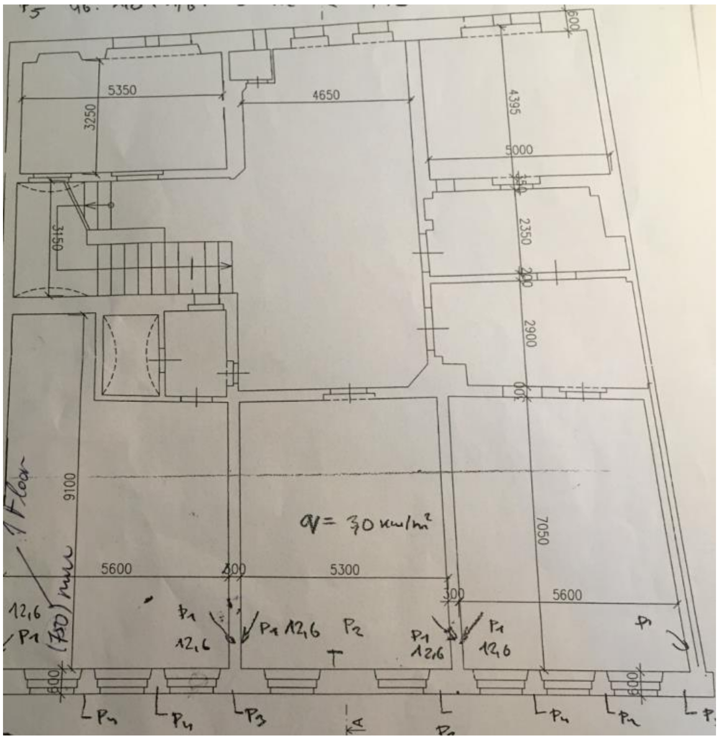
Figure 5: Dimension of Arches and Columns on Main Facade

4.2.2 Wall

Each geographical region and period in history has had its own characteristic way of building walls [3]. The historical building Strahovská FARA has lateral and longitudinal walls at west and east side of main façade. Those walls connected with east and west neighbor buildings (See Appendix A). The dimension and thickness of ground and second floor of building 1 including lateral and longitudinal walls can be shown in Figure 6. As shown in Figure 6, the thickness of walls is approximately 0.8 to 0.95m.



Plan of Ground Floor



Plan of Second Floor

Figure 6: Autocad Plan of Ground and Second Floor of Building 1

4.2.3 Building Material

The building Strahovská FARA is made of mixed masonry, which contains bricks, opuka, mortar and its covered by plaster and render. The opuka stone is one of the large used construction material in this building. The opuka stone can be described as a compacted fine-grained sedimentary rock from the Cretaceous age, which is usually of yellow brown to beige color, but also gray or gray-blue [9]. The opuka stone contains varying properties of calcite, silica and clay minerals. In the case of building Strahovská FARA, the main mechanical property of opuka is different when it is under perpendicular and parallel load bearing position. When the opuka stone contains high level of moisture content, it has problem of delamination. Meanwhile, when the opuka stone is extremely dry (low level of moisture content), it would have high powder-rate on its surface. Specifically, the opuka stone would suffer issue of material detachment if the moisture content is excessive high or low, which can directly influence its mechanical property.

Due to the major deterioration occurred at main façade of building Strahovská FARA, one meter of drilling test has been done by Ing. Lumir Caithaml 2016 [10]. The material of supporting column can be shown in Figure 7.

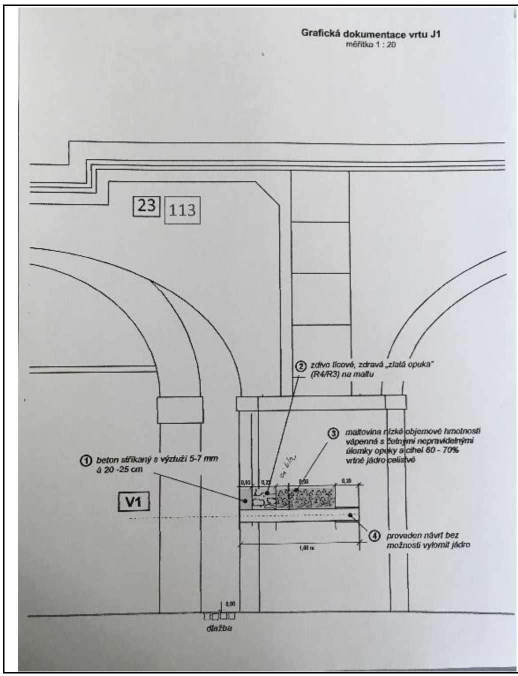
<table>
<tr><td rowspan="3">
</td><td>① Concrete surface (5-7cm)</td></tr>
<tr><td>② Good masonry of yellowish opuka (7-25cm)</td></tr>
<tr><td>③ Lime mortar with low strength, 60% to 70% of opuka and bricks (25-100cm)</td></tr>
</table>

Figure 7: Materials of Column on Main Façade [Ing. Lumir Caithaml, 2016]

5. Site Survey

During site visits in the period from April to June 2017, visual inspections were performed and collected important and valuable information from the historical building Strahovská FARA, in order to do the further assessment of the structure. With an engineering measurement type, artificial light, crack meter and a laser meter during the historical investigation, information was collected for a photographic documentation and geometrical survey, which can be complied and organized in the proceeding section.

5.1 Photographical Documentation

A number of photographs were taken during site visits, in order to visualize damages and geometry of the building Strahovská FARA.

Note: to orient the viewer, all photographs presented in the report have been numbered and labeled generally in map (See Figure 8). All photographs and brief descriptions are included in Appendix A.

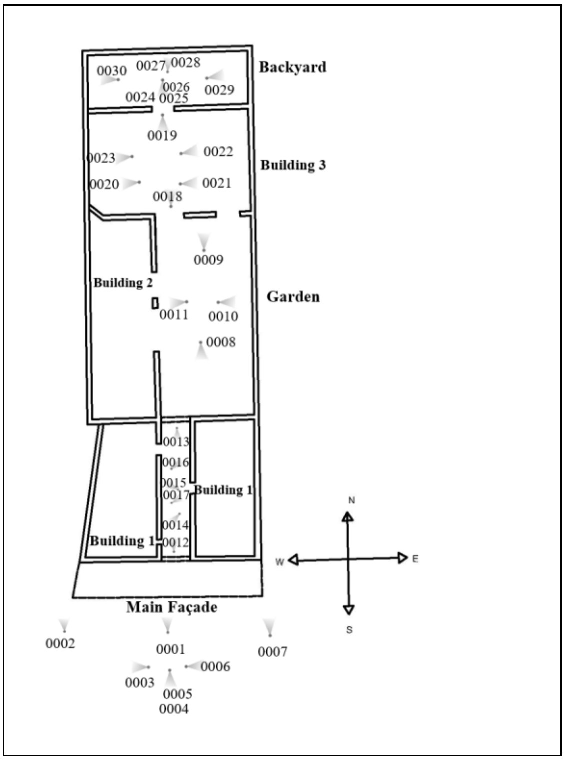


Figure 8: General View of Photographic Documentation

5.2 Geometry

The historical building Strahovská FARA consists of three conjunction buildings and an interior garden (See Figure 9). Each of conjunction buildings are connected.

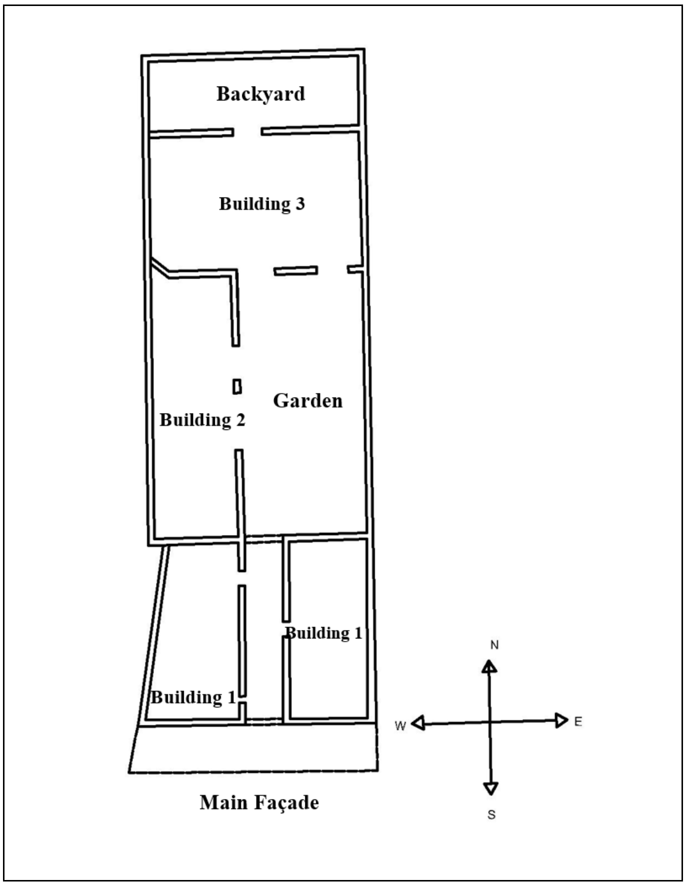
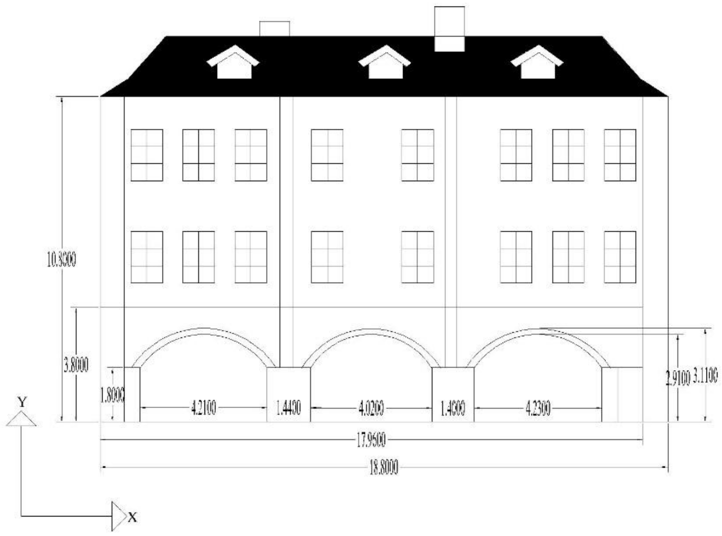


Figure 9: Gemetrical Plan of Building Strahovská Fara

5.2.1 Building Strahovská FARA

The main facade of building Strahovská FARA faces to the square of Pohořelec which is a busy traffic area next to Prague Castle. The main facade contains with one arcade which includes 3 arches with 4 columns (see Figure 10). Around garden area, it contains 3 conjunction buildings, garden and backyard (see Figure 11). The total area of the garden is approximately 216 meter-square, which is surrounded by conjunction buildings.

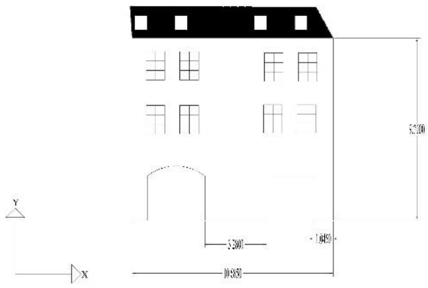
Site Picture of Main Facade



Plan of Main Facade

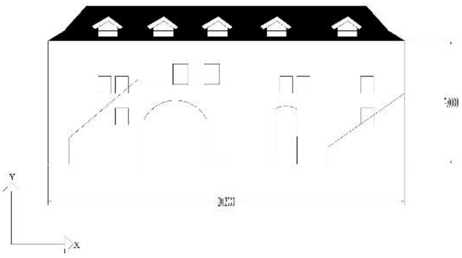
Figure 10: Main Facade with Geometrical Plan

North of Garden

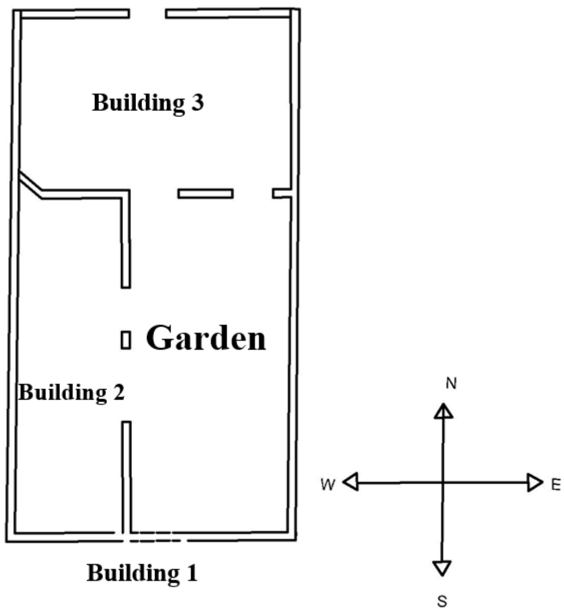


Plan of North Garden

West of Garden

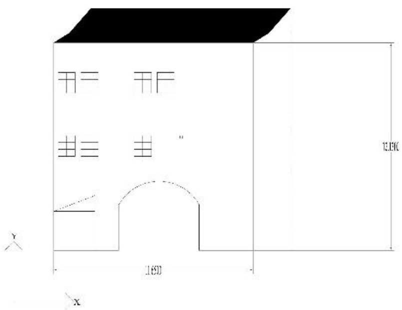


Plan of West of Garden



Garden Plan

South of Garden



Plan of South of Garden

Figure 11: Interior Garden and Conjunction Buildings with Dimensions

5.3 Geological Conditions

The main decay of the building Strahovská FARA is related with high content of moisture. The geology features of building Strahovská FARA were analyzed for understanding the root of this problem, and it pays attention to the direction and depth of underground water, foundation condition and materials under the column of main façade.

According to the geological technical report, the underground water flows from Bila Hora (in English White Mountain, western part of Prague) to the river Vltava valley (see Figure 12) (Geotechnical Report; Ing. Lumir Caithaml, 2016 [10]). The direction of groundwater is indicated on the Figure 12 with red arrow, and the depth of underground water is between 12 to 14 meters (Geotechnical Report; Ing. Lumir Caithaml, 2016 [10]). Although the location of building Strahovská FARA is on the top of the hill, it still has problem of wetted slate with part of clays under the building, which are saturated from underground water Bila Hora.

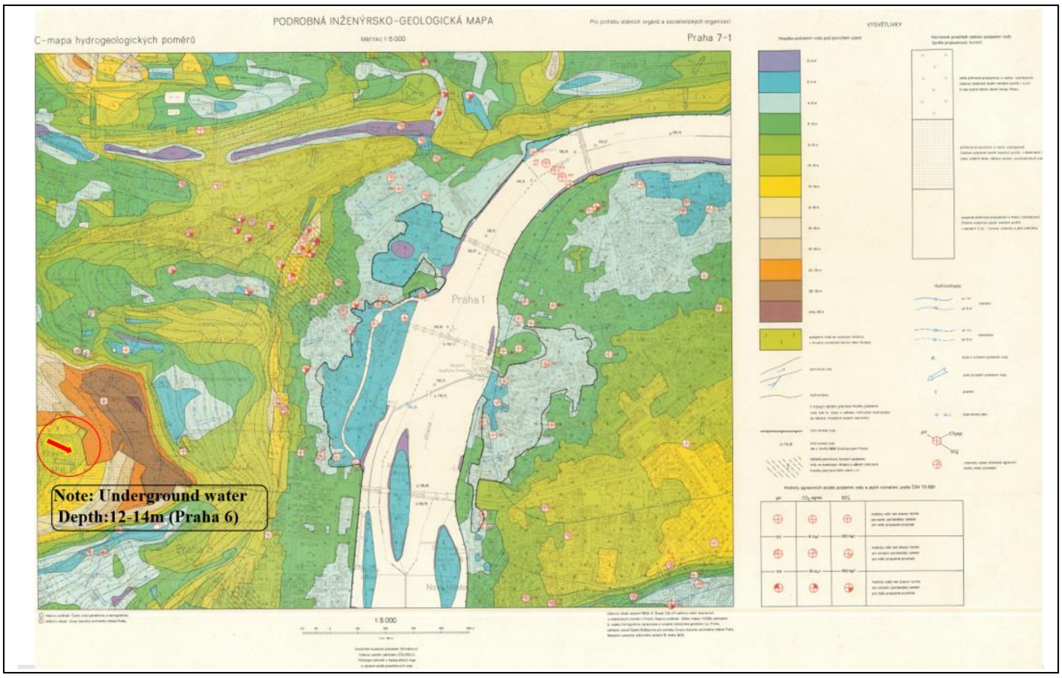
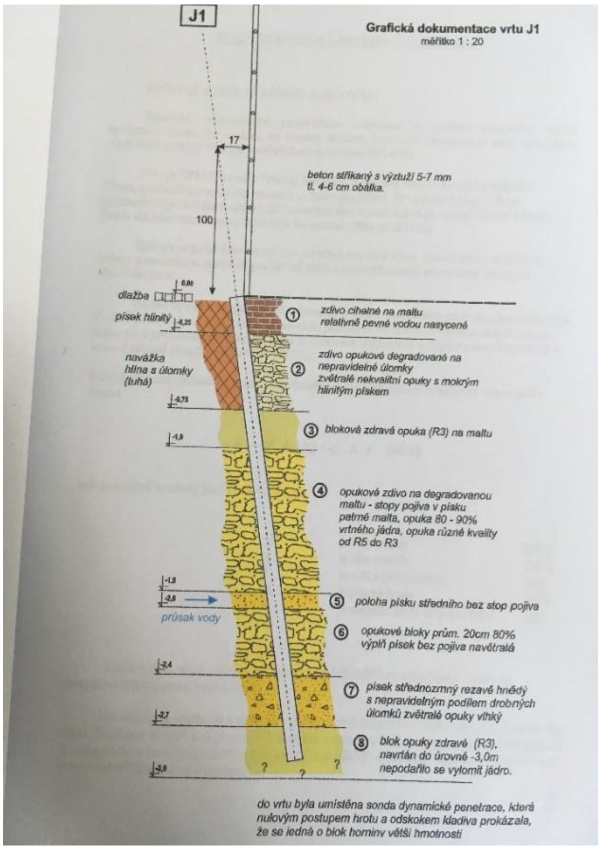


Figure 12: Groundwater Direction and Depth (Praha-Petrin-Gevy c u 0385 1248 z 12 1985(P 37 611); Ing. Lumir Caithaml, 2016 [10])

The rock base of the Pohořelec area is black gray claystone with coal. A drilling test has been taken next to the column of main façade with drilling bore J1 (see Figure 13) (Geotechnical Report; Ing. Lumir Caithaml, 2016 [10]). The total depth of drilling is 3-meter-deep from the terrain. The underground material below the column of main façade can be shown in Figure 14. Based on the data in geotechnical report, the major problem of foundation and columns is the degraded opuka stone between the depth of 0.25 meter to 0,75 meters, due to the moisture (Ing. Vaclav Jandacek [11]).



①: (0-0.25m) Brick masonry with saturated mortar
③ : (0.25 -0.75m) degraded opuka
④ : (0.75-1.0m) good opuka
④: (1.0-1.9m) good opuka with degraded mortar
⑤ (1.9-2.0m) sand without boundary
⑤ (2.0-2.4m) 80% opuka and 20% sand
⑥ (2.4-2.7m) sand with unregular small part of opuka
⑧: (2.7-3.0m) massive soil of natural condition

Figure 13: J1 Drilling test of Foundation (Geotechnical Report; Ing. Lumir Caithaml, 2016 [10])

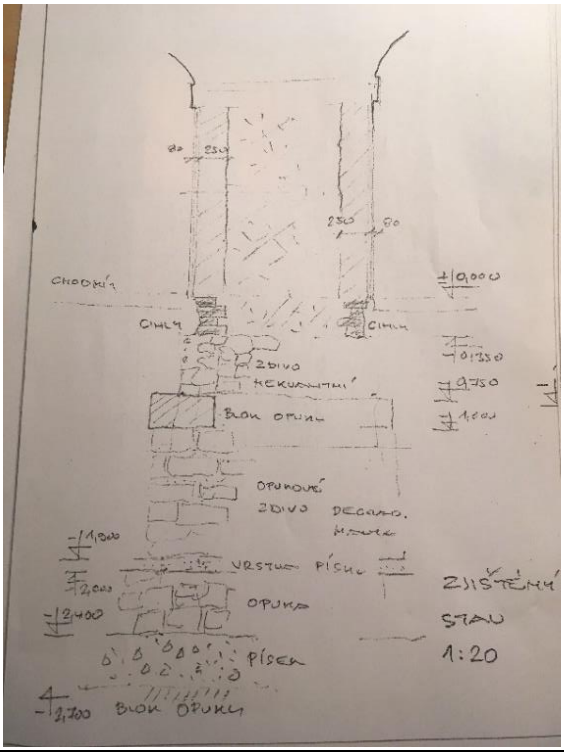
<table>
<tr><td rowspan="7">
</td><td>1. (0-0.35m) bricks</td></tr>
<tr><td>2. (0.35-0.75m) bad quality masonry</td></tr>
<tr><td>3. (0.75-1m) good quality opuka block</td></tr>
<tr><td>4. (1.0-1.9m) opuka masonry</td></tr>
<tr><td>5. (1.9-2.0m) sand layer</td></tr>
<tr><td>6. (2.0-2,4m) opuka</td></tr>
<tr><td>7. (2.4-2.7m) sand and sandstone</td></tr>
</table>

Figure 14: Materials under Columns of Main Façade (Geotechnical Report; Ing. Vaclav Jandacek, 2016 [11])

6. Failures of Structures and Material Deterioration

The historical building Strahovská FARA was investigated through visual inspection from the time (April 2017 to June 2017). In-depth damage, decay and degradation, and crack surveys were conducted to record the current state of structure. The mechanism of degradation and decay includes mechanical external deterioration, material deterioration, chemical deterioration and bio-deterioration [12]. More causes of decay can be seen in Appendix B.

1. Mechanical External Deterioration

Mechanical external deterioration is caused by excess of stress with respect to the strength of the material [12]. The excess of load and stress could be caused by transport or working techniques, thermal expansion and dynamic load.

2. Material Deterioration

The material deterioration is caused by a physical variation of water inside of masonry [12]. The effect of physical variation of water consists of evaporation, capillary flow, freeze or thaw, and salt crystallization within the pores.

3. Chemical Deterioration

The Chemical deterioration is caused by the material deterioration contaminated by salts (sulphate, nitrate and chloride) in the masonry. This chemical reaction of erosion requires the existence of moisture or the presence of water. When the water is in form of liquid and vapor, the chemical reaction is chemically active and the water vapor can act as a transport of medium for other components [12].

4. Bio-deterioration

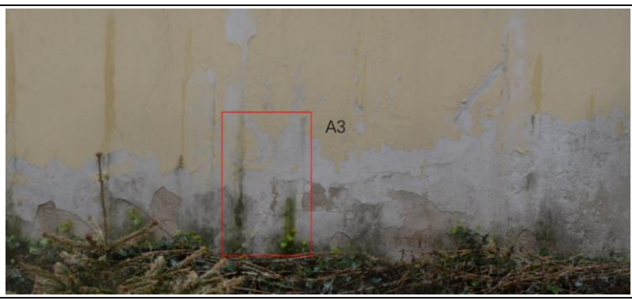
The bio-deterioration is mainly caused by algae, molds and insects. This deterioration can weak the material of building and cause damages to building. For instance, moss can penetrate several millimeters of the material surface and weak material strength.

6.1 Inspection and Diagnosis of Damage and Decay

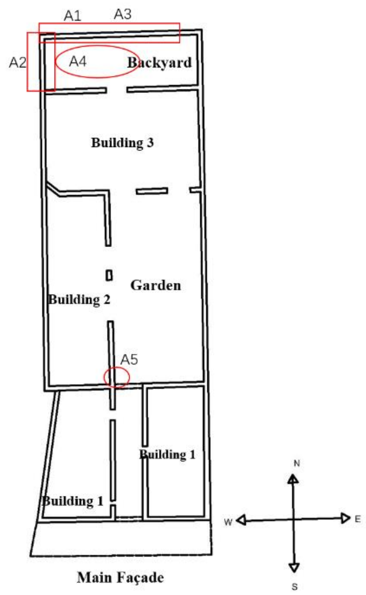
The location of deterioration was indicated throughout the historical building Strahovská FARA. In this case, it is obvious that the problem of bio-attack and physical deterioration are related with moisture problem, and salt crystallization within the pores.

6.1.1 Bio-Deterioration & Alteration

Plants and mold are main agents of bio-deterioration for the historical building Strahovská FARA (See Figure 15 & 16). Although bio-deterioration would not cause structural issue to the building, they would affect its aesthetics. Main reasons of bio-deterioration are lack of maintenance and moisture.



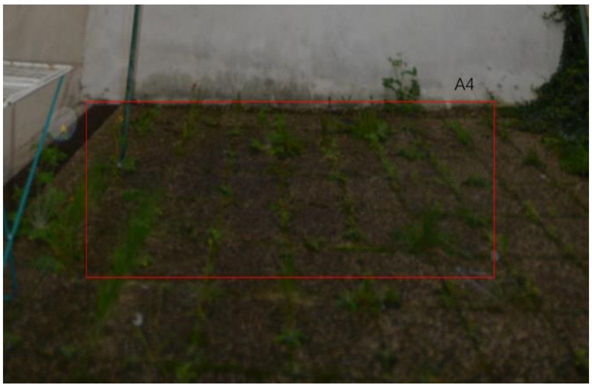
A1;A3: Mold and Algae

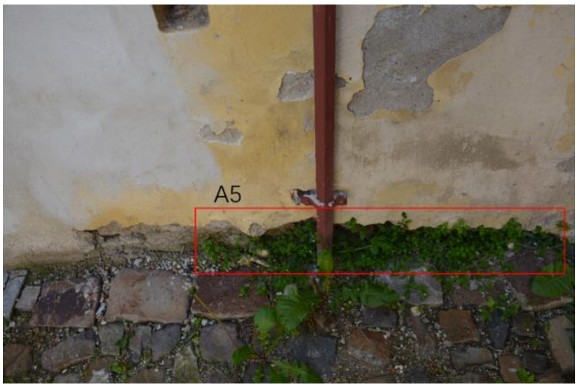


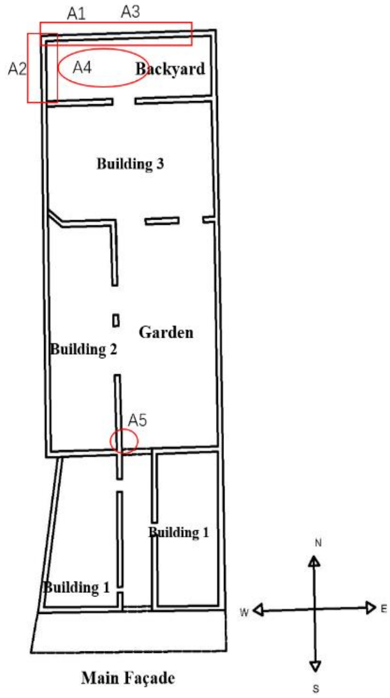
Location: A1 and A3 are located at backyard of the building

Diagnosis: A1 is due to the splashing water from the edge of right-side electrical masonry box; A3 is due to the ground moisture and rain water. Both deteriorations can also be affected by lack of maintainence. Biologicially, mold and algae can be caused by Penicilium or Aspergillus Niger.

Figure 15: Bio-deterioration by Mold and Algae







A2;A4;A5: Plants

Location: A2 and A4 are located at backyard of building. A5 locates at back side of Building 1

Diagnosis: A2,4,5 are due to rain water and lack of maintainence. Bilogicially, mold and algae can be caused by Penicilium or Aspergillus Niger.

Figure 16: Bio-deterioration by Plants

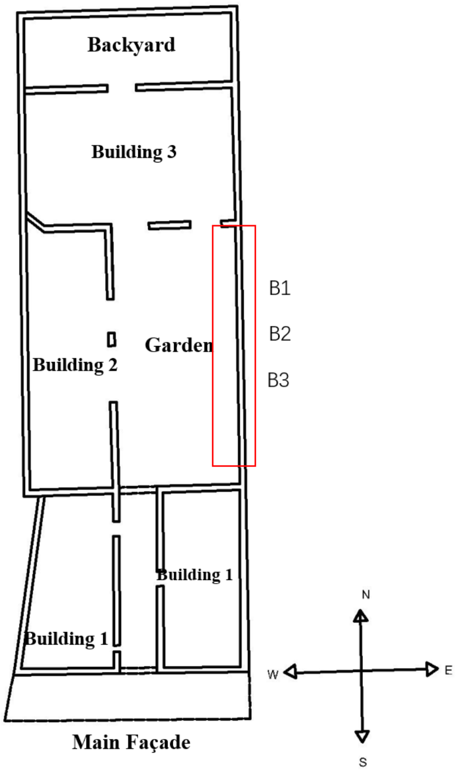
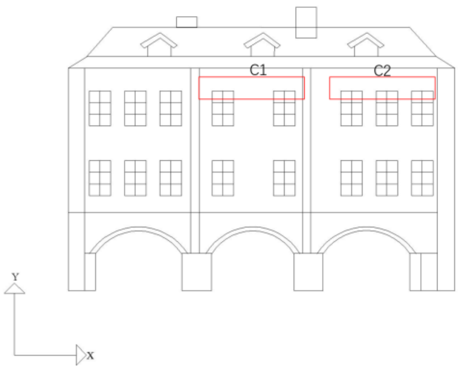
<table>
<tr><td>
</td><td rowspan="4">
</td></tr>
<tr><td>
</td></tr>
<tr><td>
</td></tr>
<tr><td>B1;B2;B3：Black Patina (Mold and Algae)</td></tr>
<tr><td colspan="2">Location: B1,2,3 are located at east-side garden under chimneys</td></tr>
<tr><td colspan="2">Diagnosis: B1,2,3 are caused by rain water flowing through those chimneys. Molds occurs on the wet masonry of wall. Bilogicially, mold and algae can be caused by Penicilium or Aspergillus Niger.</td></tr>
</table>

Figure 17: Bio-deterioration by Black Patina

6.1.2 Mechanical External Deterioration

The effect of mechanical external deterioration in Building Strahovská FARA is material detachment which generated different sizes of crack on main façade (See Figure 18). Although the effect of mechanical external deterioration in this case would not cause structural issue, it affects its aesthetics. In this case, only medium and large size cracks have been analyzed, and the definition of crack size is shown in section 6.1.4.

C1; C2: Mechanical Deterioration



Location: C1 is located at middle facade of upper windows, C2 is located at upper windows of east-side main facade.

Description: C1 includes 2 medium size cracks and 2 large size cracks along with the material detachment area next to the upper windows. C2 has 4 material detachment regions and 2 medium size cracks along with upper window.

Diagnosis: The reason of those cracks is complexed, but the main reason is the unfinishing window frame. Other possible reasons could be lack of maintenance, differential settlement and traffic influence such as dynamic motion caused by automobiles. Mechanically, this deterioration is related with stress factor on the building.

Figure 18: Mechanical External Deterioration of Main Facade

6.1.3 Material Deterioration

The material deterioration is caused by moisture and salt crystallization within the pores for historical building Strahovská FARA. Most of materials should contain a suitable volume of moisture content as a component of the molecular constitution, and it has certain level of moisture content limits. When the moisture content of material reached excessive level, the strength of material would be critically decreased. If the surface layer of material could not evaporate the excessive level of moisture inside the masonry, it turns out to be a structural problem which could affect different positions of structure. In this case, most of moisture problems are caused by missing DPC (damp proof course) or other moisture removing measurements. Additionally, the problem of salt crystallization is related with previous usage of building 3. Major categories of moisture problem include rising damp and splashing water (penetrating damp).

Specifically, the main façade of building has critical problems of rising damp with combination of splashing water, which cause material detachment and weakens the load bearing capacity of supporting columns (See Figure 20, 21). Building 1,2,3 and backyard have different damage level of splashing water and rising damp problem (See Figure 22-26). Salt crystallization have been observed on masonry wall at interior of building 3, which weaken the strength of opuka and bricks (See Figure 27).

Rising damp is the result of water being drawn up into porous masonry from wet ground by capillary action [2]. The diameter of porous in masonry is the major influencing factor of the level of capillary action. When the porous diameter is reach to $10^{-5}m$eter, it has high capillary action with water raising up to a height of 1.5 meter [15].

Penetration damp (splashing water) is that the water ingress through masonry above or below external ground level, is usually the result of faulty rain water goods or roof coverings [2]. The damage level of penetration damp based on the severity of the conditions of exposure of the structure and the porosity of material.

Salt contamination occurs when the presence of water mobilizes soluble salts in solution. When water evaporates, salt crystallize remains inside the porous of the masonry, and this process generate crystallization pressure and cause damage. If the pore of material is filled by salt with high thermal expansion coefficient, crystallization pressure could bring damage to the structure. The most serious problem of salt crystallization is the cyclic presence of water with continuously generating crystallization pressure against the pore wall.

The moisture can infiltrate masonry in 5 different ways (see Figure 19) [13].

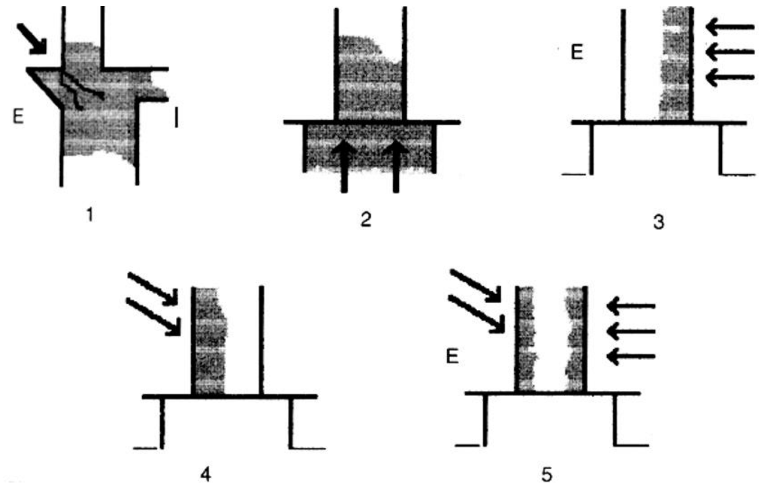


Figure 19: Ways of Moisture Sources to The Building [13]

1. Infiltration due to damage in the structure or mainly horizontal surface

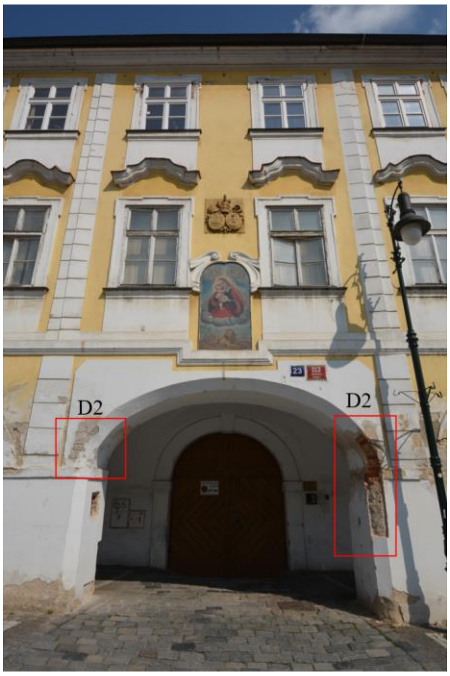
2. Ascension by capillary from underground

3. Surface condensation or air humidity on cold walls (Thermal Bridges)

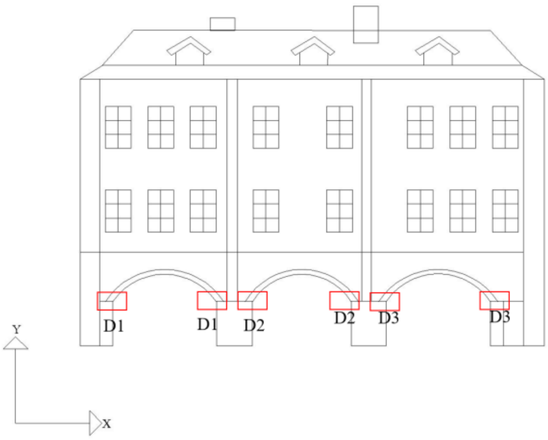
4. Rain water driven by wind

5. Diffusion (mostly during the year, the direction of diffusion is from interior to exterior of masonry)

a. Main Facade



D1;D2;D3: Rising Damp



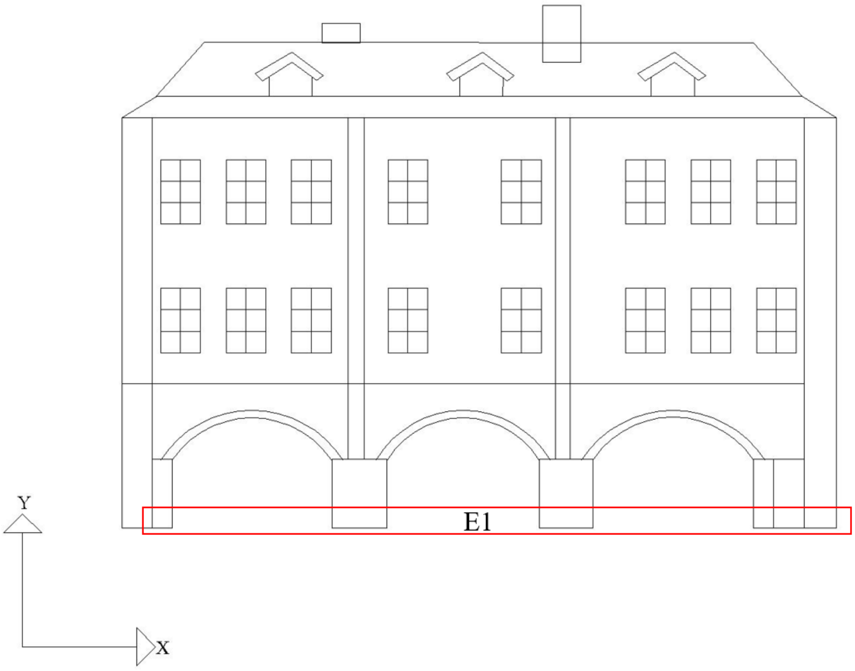
Location: D1,2,3 locate at connection part between columns and arches on the main facade

Description: from east side to west side of main facade, 4 load bearing columns have problem of material detachment.

Diagnosis: the rising damp of D1,2,3 is due to the previous restoration of main facade. The surface layer of each column has 5 to 7 centimeter thickness of concrete layer, which do not allow the evaporation of water, due to the impermeability of concrete material. As the ascension of groundwater from the terrian to arches' rib, rising damp evaporate slowly in the moisture zone above concrete layer.

Figure 20: Rising Damp on Main Facade

E1: Splashing Water and Rising Damp



Location: E1 locates at the bottom part of main facade

Description: four load bearing columns have different level of material detachment at bottom part.

Diagnosis: rain water splash on the bottom columns by wind and roof during heavy rainy period, and water can transport from underground to inside of masonry by capillary action. Due to lack of DPC at bottom part of columns, water comes from underground damaged drainage system and penetrates easily into masonry and cause damage. On the other hand, due to the slop of terrian, rain water flows from left-side column to right-side column, which brought bigger damage at two middle columns and right-side column.

Figure 21: Water Splashing and Rising Damp on Main Facade

b. Garden Area

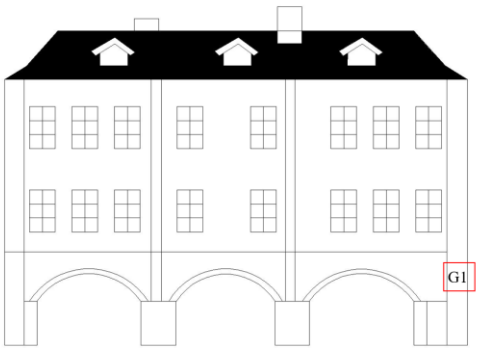
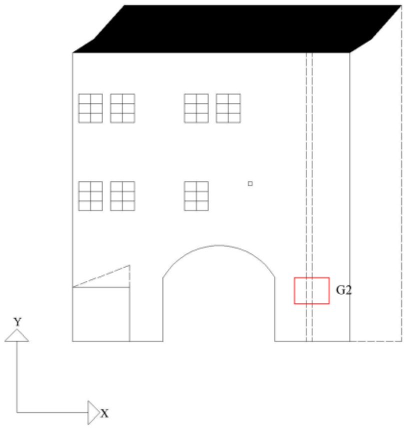
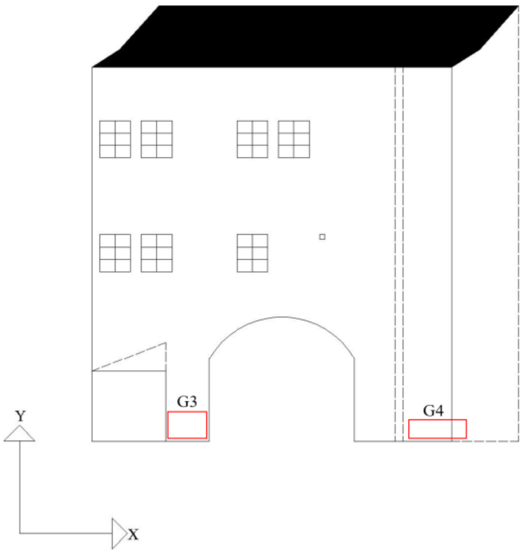
	
G1; G2: Leaking	
	
Location: G1is located at right-side of main facade. G2 is located at back side of building 1 around the drainage pipe.	
Description: G1 and G2 have the problem of material detachment. The level of material detachment of G1 is more servious than G2.	
Diagnosis: G1 is caused by leaking of drainage pipe at right side of main facade. Rain water splash out during the rainy period. Rain water can penetrate into masonry wall and cause damage. During the inspection, the drainage pipe around G2 seems new. Thus, G2 is caused by leaching from previous drainage pipe.	

Figure 22: Leaching from Drainage Pipe on Building 1

G3; G4 : Splashing Water and Rising Damp



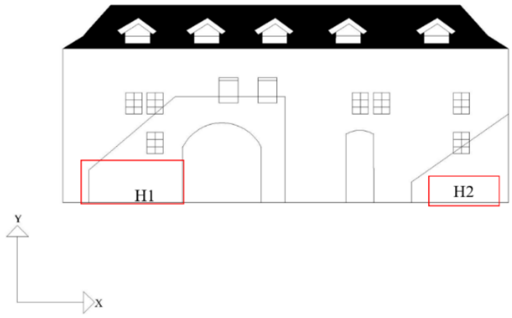
Location: G3 and G4 are located at the back side of building 1.

Description: G3 and G4 shows different level of material detachment. The damage of G4 is approximately 1.4 meter from right side of drainage pipe to the right edge of building 1.

Diagnosis: G3,4 are mainly caused by the falling water from roof during heavy rainy period. G4 are mainly caused by missing DPC, and moisture transport from underground to masonry by capillary action.

Figure 23: Splashing Water on Building 1

H1; H2: Water Splashing and Rising Damp

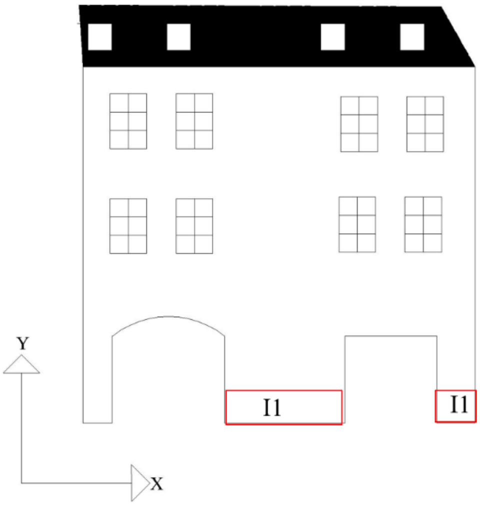


Location: H1 and H2 are located at left and right side of the Building 2. H1 is on the left exterior staircase, and H2 is on the right exterior staircase.

Description: H1,2 appear problem of material detachment. For H1, material detachment is along with the left exterior staircase. The rising damp area of H1 is rising to a level of 1.5 meter up to 2 meter.

Diagnosis: H1 is related with material problem of poor details. H1,2 are affected by splashing water since heavy rainy period. On the other hand, due to the slop of terrian, water flow through underground drainage system at front of staircase from left to right. Water in the damaged drainage system could penetrate inside masonry and rise up. Additionally, soil at front of H2 contain high amount of moisture during rainy period. Moisture in the soil can rise and cause damage.

Figure 24: Water Splashing and Rising Damp on Building 2

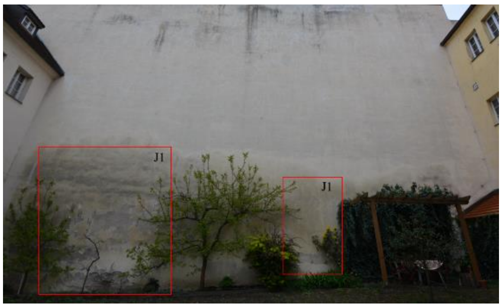


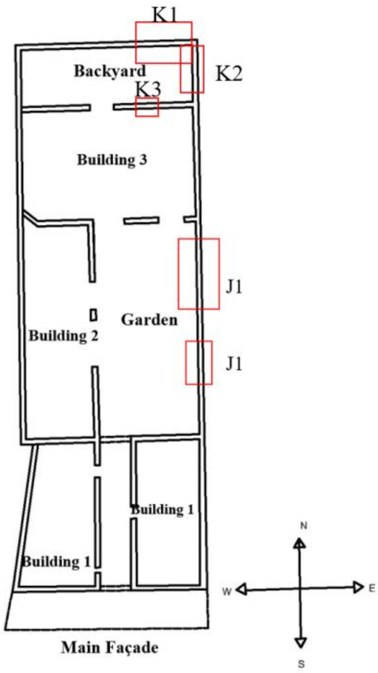
I1: Rising Damp

Location: I1 is located at bottom part of Building 3.
Description: 2 material detachment area have been observed. The damaged area between two entrances of building 3 is more serious than others.
Diagnosis: I1 is mainly caused by rising damp. Due to lack of DPC at bottom part of I1, and moisture can penetrate easily into masonry from underground by capillary action.

Figure 25: Rising Damp on Building 3

c. Wall





J1; K1; K2; K3: Rising Damp

Location: J1 is located at right side lateral wall in garden, and K1,2,3 locate at Backyard.

Description: J1,K1,2,3 shows different level of matrial detachments. J1 and K2 have lage damaged area including cracks and material detachments. K1 and K3 have problem of material detachment, but the damage level of K3 is more servious than K1.

Diagnosis: Those deteriorations are mainly caused by lack of DPC. Soil area front of those damaged regions can absorb high contents of moisture, when it is rainy day. The moisture can transport from underground to masonry wall by capillary action.

Figure 26: Rising Damp on Walls

d. Salt Crystalization

Salt Crystalization
Location: the problem of salt crystalization have been found at storage room inside of Building 3.
Description: large amont of salt have been generated on the wall in the Building 3. Some of areas affected by salt are detachable.
Diagnosis: in this case, the salt crystalization can be caused by the previous use of the building and missing DPC at bottom part of masonry wall. In order to obtain further detailed result of salt in this case, spectrophotometric test has been proposed in laboratory tests (See Section 6.2).

Figure 27: Salt Crystalization

6.1.4 Static Inspection and Diagnosis of Cracks

A detailed crack survey of the whole building Strahovská FARA was performed, including the main façade, vaults, arches, Building 1,2,3, backyard, and lateral wall. Damage identification was done by means of visual inspection from April 2017 to June 2017. Based on this inspection, some cracks in the building seem passive, because those cracks have been there for a long times and large amount of black crust have been observed inside of some reachable cracks. However, further tests have been proposed in intervention section, in order to clarify passive and active crack (See Section 8). Additionally, the depth of crack has been classified into 3 categories which are thin, medium and large size (See Figure 28).

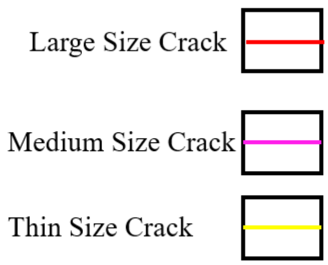
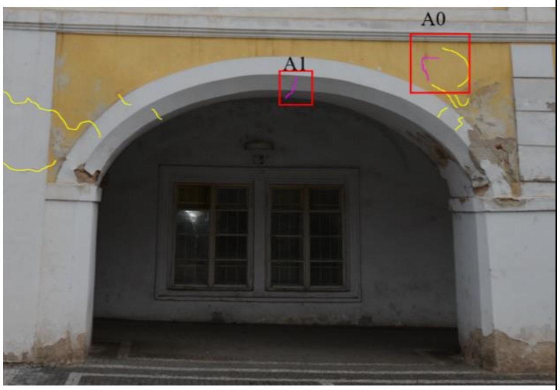


Figure 28: Crack Classification

The large-size crack means that the crack width is extremely obvious and clear, and it is highly possible to cause structural issue. Medium-size c rack means that the crack width is obvious, which contains a crack width of the range (equal or bigger 0.4-millimeter width). Thin-size crack means that the crack would not bring any structural effect but aesthetic influence. Due to minor or destructive structural effect of thin crack, medium and large size, most of cracks have been analyzed at following report, but thin cracks have been marked for future analysis if needed. For cracks that were easily accessible, the width of the crack was measured by using crack meter. Crack is the pattern of fracture due to the pressure set up when the building is not able to tolerate movement [14]. Cracks occurred when the structure of building has structural movements which could be affected by cyclic effects, physical attack (wind and water erosion), weakness of foundation, overloading of the structure, and poor quality of material. Structure features such as arches, domes and cross vaults, crack could happen in the structural stabilization process. Shear and tensile cracks are very common in the masonry building, which normally be influenced by soil settlements and inherent design properties. Diagonal cracks indicate shear generally resulting from unequal settlement, and vertical crack wider at the top can mean that the wall is moving outward [3]. Main reasons of cracks on the building Strahovská FARA are irregular shape of arches, soil settlement, weak-load bearing columns and less-effective wall with low-strength material (See Figure 29-35). The crack analysis guidelines can be seen in Appendix C.

a. Main Facade & Arcade



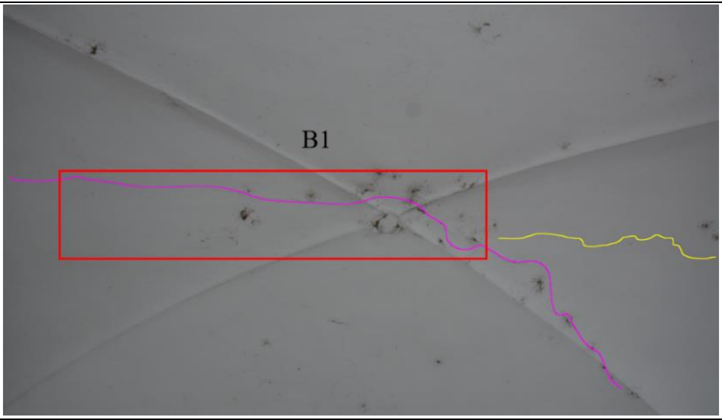
A1,2,3: Cracks on Arches

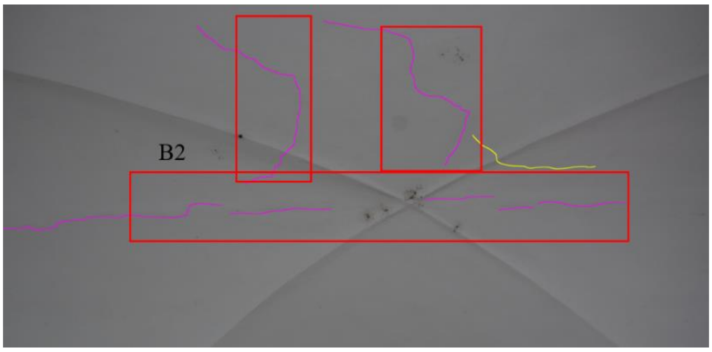
Location: A1,2,3 are located at middle of arches on the main façade. Around A1,2,3, there are two medium size cracks (See Crack A0).

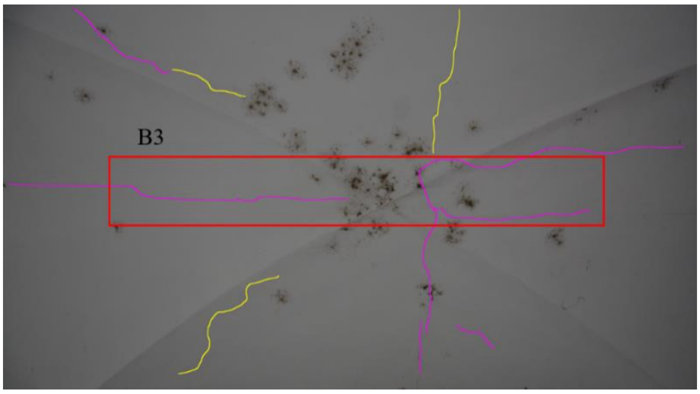
Description: 3 cracks can be obviously observed on middle of the arches at main façade, and the size of each crack can be considered as medium. Around 3 cracks, 2 medium-size cracks and several thin-size cracks appears.

Diagnosis: A1,2,3 are hinges of arches on the middle, and they are caused by the irregular shape of arches. These 3 arches have long span with short raise, which generate hinge of the arche for structurally equilibrium. Meanwhile, due to differential settlement of building and less-effective load-bearing column, A0 and A1,2,3 are formed.

Figure 29: Cracks on Main facade

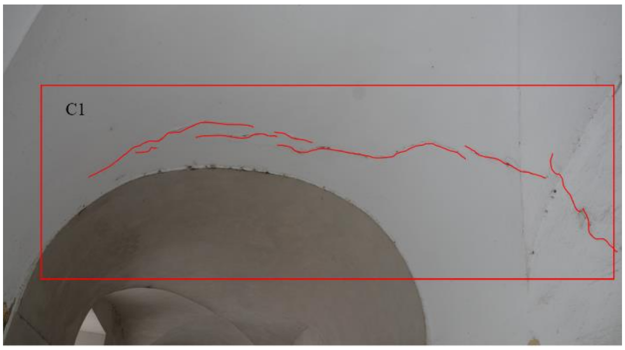


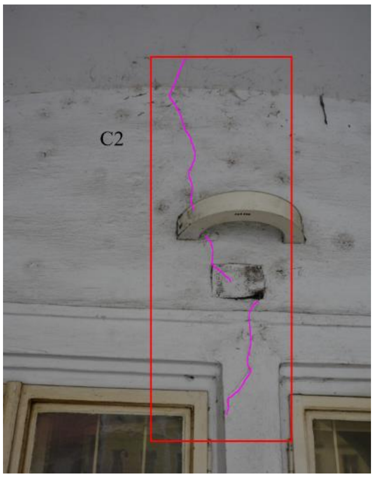


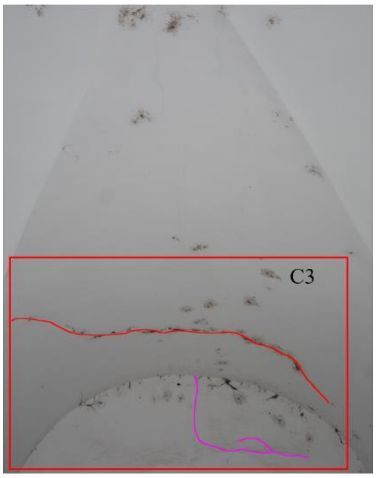


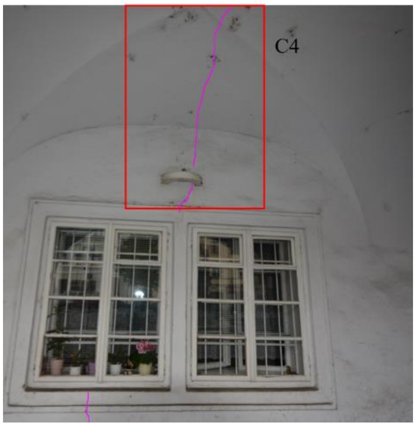
B1,2,3: Longitudinal Crack & Vertical Cracks
Location: B1,B2,B3 are located at gothic vaults above the arcade. B1 is on the first vault of left side building. B2 is on the middle vault, and B3 is on the east-side vault of building.
Description: Several longitudinal cracks with medium and thin size have been observed on vaults. At the second vault of B2, it contains 2 parallel vertical cracks with medium size.
Diagnosis: those longitudinal and vertical cracks can be the problem of differential settlement and instability of columns. Due to the problem of weak material at load-bearing columns cuased by moisture, the load bearing capacity of columns decreased and can be a influential factor to generate those cracks. Additionally, soil settlement of foundation could also affect vaults and generate cracks.

Figure 30: Longitudinal and Vertical Cracks on Vaults









C1,2;C3,4: Horizontal and Vertical Cracks

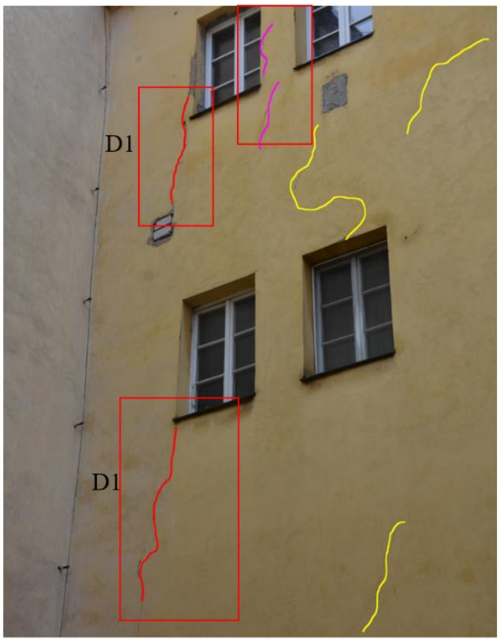
Location: C1,2 are located at left side vault above the arcade, and C3,4 are located on the right side vault of main facade.

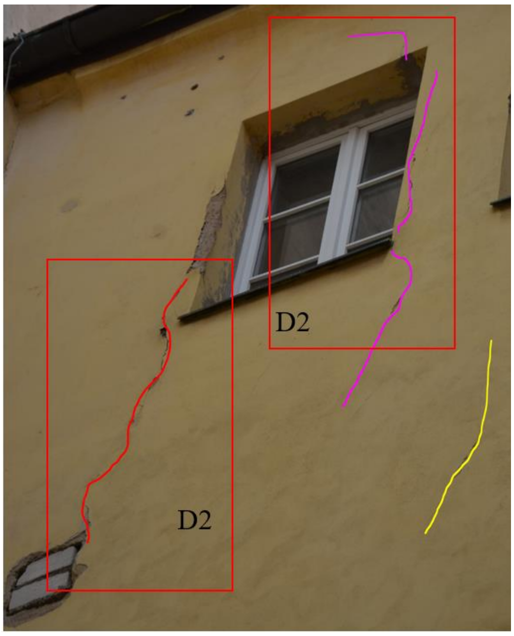
Description: C1,3 are horizontal cracks with large-size and long length. C2,4 are vertical cracks with long length and medium size, which are along with interior window openings.

Diagnosis: C1, 3 are caused by the settlement and the movement of subsoil. C2,4 is caused that vaults are not fixed enough. The appearance of C1,2 is related with the movement of differential settlement between left-side neighbor building and main facade of Strahovská FARA. The appearance of C3,4 is related with the movement of differential settlement between reft-side neighbor building and main facade of Strahovská FARA

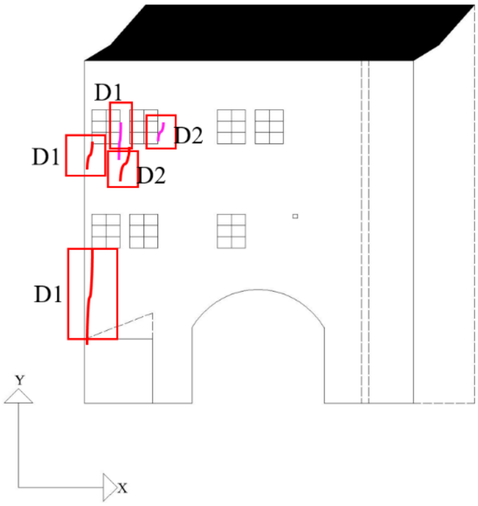
Figure 31: Horizontal and Vertical Cracks on Arcade

b. Back of Building 1





D1;D2: Diagonal Cracks



Location: D1,2 are located at left of back-side of building 1, near the right side neighbor building.

Description: D1,2 are diagonal and vertical cracks with large and medium size and long length. Several thin cracks are around D1,2.

Diagnosis: D1,2 are caused by the settlement of soil movement. These two buildings are properly fixed with each others and cause the cracks.

Figure 32: Diagonal Cracks on Building 1

c. Building 3

Location: E1 are located on the long-span arch in the interior of Building 3.
Description: E1 have medium size and long length, which is along with the edge of arche.
Diagnosis: E1 are caused by the geometry of arche, because the interoir arche in Building 3 has long span with small raise.

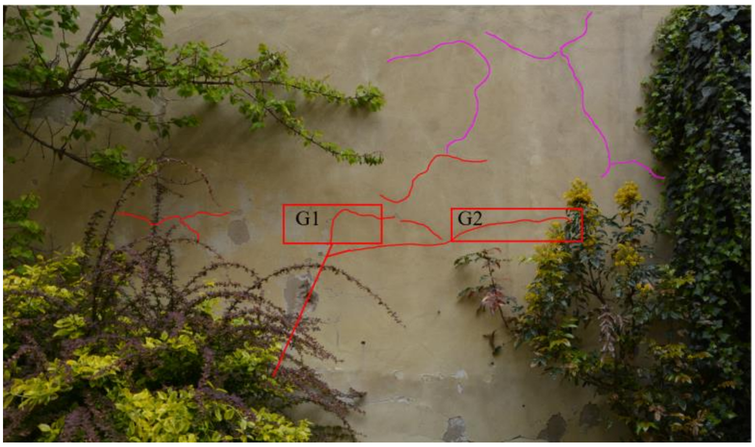
Figure 33: Crack on Interior of Building 3

d. Backyard

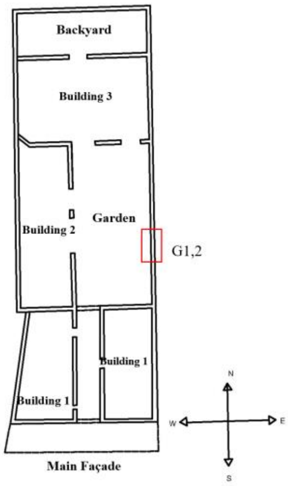
Location: F1 are located on the back side of Building 3 next the right side of entrance in the backyard. The direction of those cracks shows vertical and diagonal.
Description: the large size crack F1 has been observed.
Diagnosis: F1 is caused by the soil settlement.

Figure 34: Crack on the Back Side of Building 3

e. Lateral Wall



Width of G1	Width of G2



Location: G1,2 are located at right side lateral wall in the garden.

Desccription: Several different cracks on the wall have been observed, and G1,2 are cracks on the masonry wall with thickness of 0.45mm.

Diagnosis: G1,2 are mainly caused by the previous technological process, when the cement mortar was applied in big thickness.

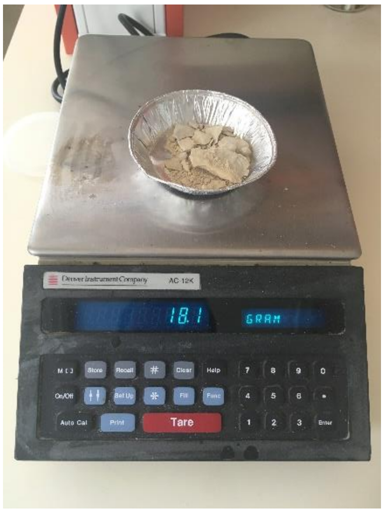
Figure 35: Crack on the Lateral Wall

6.2 Laboratory Analysis of Building Material

Most of deteriorations and crack diagnosis are based on the visual inspection and some assumptions of decays and their causes, it is critical to verify the accuracy of those assumptions. Thus, MDT (Minor destructive test) and NDT (Non-destructive Test) have been proposed, which are moisture test and spectrophotometric test. Furthermore, samplings for moisture test were taken from different areas of the site during the site visits at May 19^{th} 2017. Samples for spectrophotometric test is taken by a specific site, in order to fully evaluate physical and chemical characteristics of the stone. In addition, the micro-analysis is able to confirm some of the previous analysis. Based on the optical microscopy visualization, the salt crystallization has been verified. All tests and micro-analysis were taken at the Department of Building Structure FCE CTU (Faculty Civil Engineering of Czech Technical University).

6.2.2 Moisture Test

After the visual inspection, dampness problem is one of the major damages to the building Strahovská FARA. Although electric moisture meter is a quick tool for moisture testing of masonry surface, gravimetric analysis of moisture testing has been applied for its objective results. In order to have understandings of moisture regime of the building, 15 samples from different parts of building have been tested by gravimetric analysis (see Figure 36). All samples were taken at depth of 0-25mm, within the evaporation and deterioration zone. Figure 37 shows that samples were taken from different parts at the building Strahovská FARA. Samples were dried until constant weight.



Weighting Machine | Drying Samples in The Oven (105 ℃)

Oven

Figure 36: Moisture Test Procedure

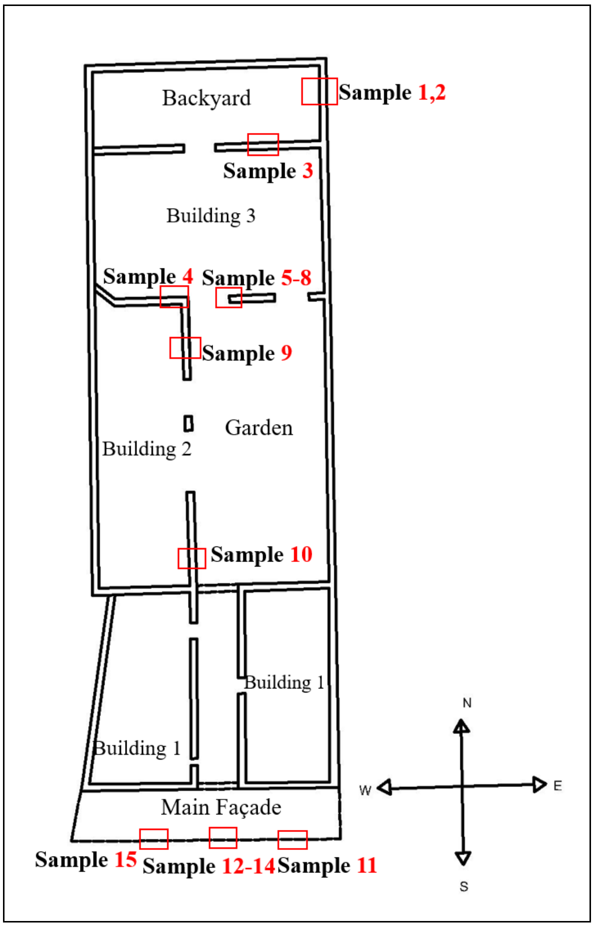


Figure 37: Samples Location

Based on measurements, the moisture content (M.C) of each sample was calculated by comparing the weight of samples before and after the drying procedure. The following moisture content calculation formula has been applied.

$$MC = \frac{w_t - w_f}{w_f} \quad (1)$$

Where

- MC is the moisture content
- w_t is the initial weight of sample
- w_f is the dried weight of sample

The classification of moisture content according to Czech Standard (CSN 730610) has shown in Table 2, which classifies the masonry dampness from very low to very high level depending on the moisture content percentage.

Table 2: Classification of Moisture Content; Czech Standard (CSN 730610)

CLASSIFICATION OF MOISTURE CZECH STANDARD (CSN 730610)		
	DEGREE	MC
(cyan)	Very low moisture	MC<3%
(green)	Low moisture	3%<MC<5%
(yellow)	Slight high moisture	5%<MC<7,5%
(orange)	High moisture	7,5<MC<10%
(red)	Very high moisture	MC>10%

The result of moisture content of each samples can be seen in Table 3.

Table 3: The Result of Moisture Content of Building Strahovská FARA(May 19th 2017)

SAMPLE N.	*t* [g]	w_w [g]	w_d [g]	*MC* [%]
1	1.6	10.8	10.5	3.37
2	1.6	11.7	11.3	4.12
3	1.6	70	68.2	2.70
4	1.6	38.5	35	10.48
5	1.6	21.3	20.8	2.60
6	1.7	19	18	6.13
7	8.5	196.1	188.7	4.11
8	8.5	284.7	275.9	3.29
9	1.6	102.8	100.2	2.64
10	8.5	126.3	123.5	2.43
11	8.5	418.7	410.4	2.07
12	8.5	44.5	42.6	5.57
13	8.4	223.1	211.5	5.71
14	8.4	22.4	21.3	8.53
15	8.4	214.7	204.3	5.31

OPERATORS	ShunLi You
DATE	19.05.2017
LOCATION	Historical Buiilding Strahovská FARA
WEATHER	Sunny Day
TEMPERATURE	around 20°C

(dark red)	BRICK
(amber)	BRICK & PLASTER
(blue)	PLASTER
(dark grey)	CEMENT MORTAR
(light grey)	OPUKA

Based on the moisture content result, the evaluation of dampness is complexed in the case of Building Strahovská FARA. The classification was done mainly with the purpose of rehabilitation of the building and to understand the moisture regime. Meanwhile, last 5 samples (sample 11 to 15) were particularly collected from three different columns in different positions of main façade. All samples have the low and slightly high moisture level except sample 4 and 14. The moisture content of materials is influenced by climate. Considering all samples were taken in dry period with atmosphere temperature of 20℃, there is no denying the fact that dampness effect is more serious on columns of main façade and building 3 than other parts of building.

6.2.3 Micro-Analysis

Based on the result of moisture test, building 3 and columns on main façade have serious moisture problem in building Strahovská FARA. According to the survey of failure and deterioration, salt crystallization within the pore of masonry wall have been observed at building 3. Salt is transported by water in the masonry year after year. The chemical analysis has been applied by using the microscope, in order to confirm previous analyses. The sample of salt has been taken from the fractured section of masonry wall, in order to be analyzed qualitative and quantitative salt level in the laboratory (see Figure 38).

5

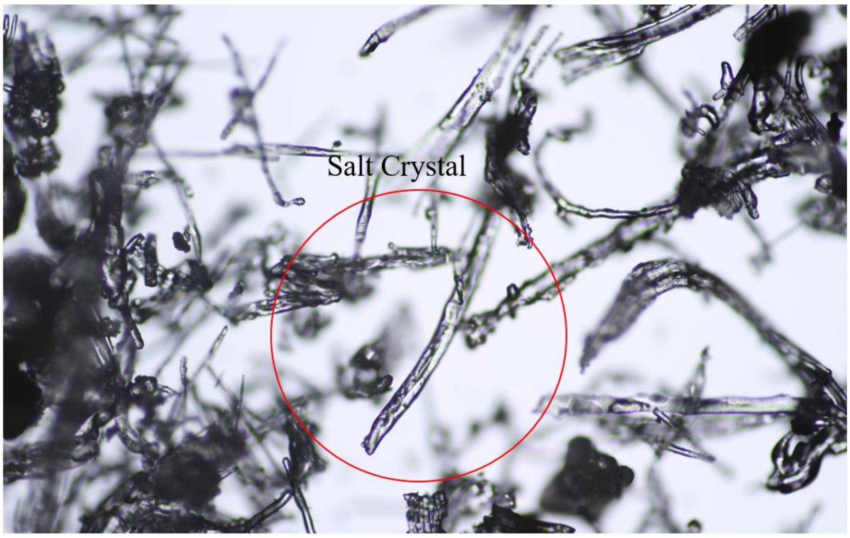
Figure 38: Salt Crystallization in-situ

After setting microscope and digital camera, two salt samples have been prepared (See Figure 39). In order to make a clear observation, one sample has been mixed with water.

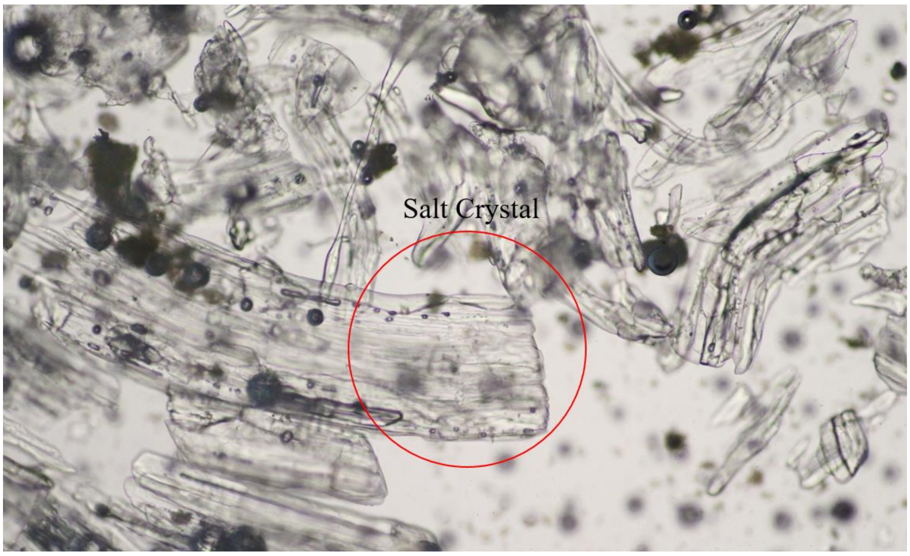
	
Laboratory OLYMPUS BX41 Microscope	Salt Sample for Analysis

Figure 39: Micro-analysis Procedure

Based on the result of chemical analysis, the presence of salt in the masonry is the result of long time process (See Figure 40). These soluble salts can last in the masonry even for hundreds of years.



Salt Sample without mixing water (X500 magnified)



Salt Sample with mixing water (X500 magnified)

Figure 40: Result from Chemical Analysis

6.2.4 Spectrophotometric Test

Based on the chemical analysis, the existence of salts is one of the main decays in the building. In order to obtain qualitative result, pH test and spectrophotometric chloride test, sulfate test and nitrate test have been applied to sample of salt crystal, sample 14 （brick） and 15 (opuka stone). Spectrophotometry is the qualitative measurement of the reflection or transmission properties of a material as a function of wavelength [16]. The concentration, hygroscopicity and type of salt can be clarified by using 3 spectrophotometric tests done by using products of Merck Company. According to the Czech Standard CSN 730610, it classifies the salt contents in masonry from low to high (See Table 4).

Table 4: Classification of Salt Contents According to CSN

Degree of Salinity	Salt Classification		
	Chlorides (mg/g)	Nitrates (mg/g)	Sulphates (mg/g)
Low	< 0.75	< 1.0	< 5.0
Medium	0.75 - 2.0	1.0 - 2.5	5.0 - 20
High	2.0 - 5.0	2.5 - 5.0	20 - 50
Very High	> 5.0	> 5.0	> 50

Chemically, pH value can define the acidity or basicity of a material or substance. Table 5 shows the pH value correspond to alkaline, neutral and acid materials. In the case of building Strahovská FARA, the pH value indicated that the structure is mainly low acidity and neutral in some areas.

Table 5: pH Indication

pH Value	
< 7	Alkaline （New Masonry)
7	Neutral
> 7	Acidity (Old Masonry)

Table 6 shows the result of salt content and classification of 3 analyzed samples.

Table 6: The Result of Spectrophotometric Test

Salt Classification							
		Chloride (Cl)		Nitrate (NO_3)		Sulphate (SO_4)	
Sample Number	pH Value	Content (mg/g)	Degree of Salinity	Content (mg/g)	Degree of Salinity	Content (mg/g)	Degree of Salinity
Sample Salt	6	0.34	Low	1350	**Very High**	22	**High**
Sample 14	7	5.7	**Very High**	6.4	**Very High**	3.3	Low
Sample 15	6.5	0.33	Low	4.25	**High**	23.5	**High**

Note: All salts have hygroscopic ability which can absorb moisture from the ground and atmosphere. When water with soluble salts partially evaporated, salts remained in the masonry pores and cause contaimination and deterioration.

---Nitrate (NO_3):. high content of the nitrate salts can be caused by the organic remains (cemetary etc.), animal urine (stables, cowshed etc.) and fertilizers.

---Sulphate (SO_4): The presence of sulphates in the building can be connected with the automobile pollution and soil and building materials.

---Chlorides (Cl): High amount of chlorides are related with de-ice winter material (NaCl). After sodium chloride melted into water, the salty water is absorbed in masonry.

The occurrence of nitrates is relatively high in those samples (samples 14, 15), which represents high risk for building material of Strahovská FARA. As written above, organic matters could be caused by previous usage of building 3.

The middle column on the main facade of building has high level of chlorides, the occurrence of chlorides are mainly caused by previous usage of de-ice material on the traffic road in winter. Later round 1990, the usage of de-ice material was forbbiden in Prague, since it has effect to historical buildings. However, in practice, the salt is still used commonly.

The east-side column contains a high level of sulphtes contamination. Pollution is mainly caused by cars, the facade was on the busy traffic road. Sulphates can be connected with the soil and building materials as well.

7. Static Analysis

Brick and opuka are main construction materials for building Strahovská FARA. Current codes of compression and bending tests with advised mechanical values of brick based on new materials, which could not efficiently present the mechanical property of historical brick. Meanwhile, the opuka stone is one of the local historical construction materials in Prague, and advised mechanical values is not able to obtain in most current codes. To adopt adequate and reasonable mechanical material properties of brick and opuka for the structural analysis model, three-point bending flexural test and compression test were applied. Additionally, the mechanical characteristics of brick and opuka are affected by their porosity and chemical composition and durability. Moisture content cannot only cause chemical degradation but also affect the mechanical property of material. In the case of building Strahovská FARA, moisture content is one of the most important parameters which immediately influence the strength and elasticity of brick and opuka in compression with uniaxial and different axial load tests.

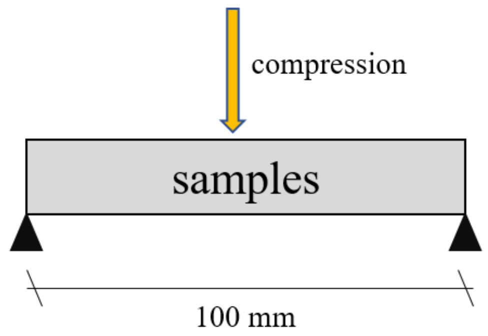
The structural numerical model of building Strahovská FARA was performed by applying the 3D-Finite Element Modeling in the program SCIA Engineering 16.1, and it was calibrated by experimental investigation. Two steps of Finite Element Analysis are included, which are Pre-processing and Post-processing. Pre-processing focus on defining the geometrical parameters and boundary conditions, model designing and meshing. Post-processing involves displaying and analyzing the result from the various analysis types.

7.1 Material Property Tests of Building Strahovská FARA

The assessment of compression strength of brick and opuka was obtained in the Mechanical Laboratory of Czech Technical University through uniaxial compression test and three point bending flexural tests on specimens of brick, dry Opuka with moisture content of 0.39 percent and wet opuka with moisture content of 10.24 percent, and all samples are collected from building Strahovská FARA. The main advantage of the three-point bending flexural test is the ease of the specimen preparation and testing, but the result of this test is sensitive to specimen, loading geometry and strain rate. Therefore, the geometry of each specimens was measured before testing. In addition, the Foce [N] – Displacement [mm] diagrams were plotted by the instrument for each sample, and the flexural strength, flexural strains and the flexural modulus were calculated in three-point bending test. Compressive strength, strain and young's modulus were calculated in compression test.

7.1.1 Three Point Bending Flexural Test

Samples of brick, dry opuka with moisture content of 0.39 percent and wet opuka with moisture content of 10.24 percent were placed on two supporting pins with distance of 100mm, and a third loading pin is lowered from above at a constant loading rate until sample failure (see Figure 41). All dimensions can be shown in Table 7.



Dry Opuka (M.C. = 0.39 %)	Wet Opuka (M.C. = 10.24 %)

Brick

Figure 41: Compression Test of triple-axial loads

Table 7: Samples' Dimension

	Length (mm)	Width (mm)	Height (mm)
Dry Opuka	160	39.93	39.85
Wet Opuka	160	41.11	40.11
Brick	160	40.60	40.74

Based on measurements, the flexural stress σ_f, flexural strain ε_f and flexural modulus E_f of each sample were calculated. The following formulas have been applied.

$$\sigma_f = \frac{3FL}{2bd^2} \quad (2)$$

$$\varepsilon_f = \frac{6D}{L^2} \quad (3)$$

$$E_f = \frac{L^3 m}{4bd^3} \quad (4)$$

- σ_f Flexural Stress

- ε_f Flexural Strain

- E_f Flexural Modulus

- F Load at Given Point on the Load Deflection Curve

- b Width of the sample

- d Height of Sample

- D Maximum Deflection of the Center Beam

- m the Gradient of the Initial Straight Line Portion of the Load Deflection

The force and displacement graph can be shown in Figure 42.

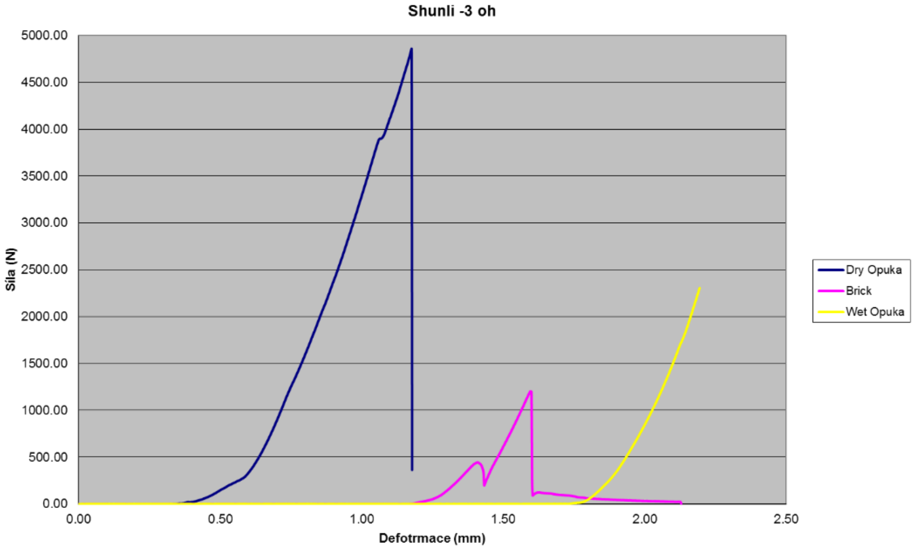


Figure 42: Force-Displacement Diagram for Dry Opuka, Wet Opuka and Brick

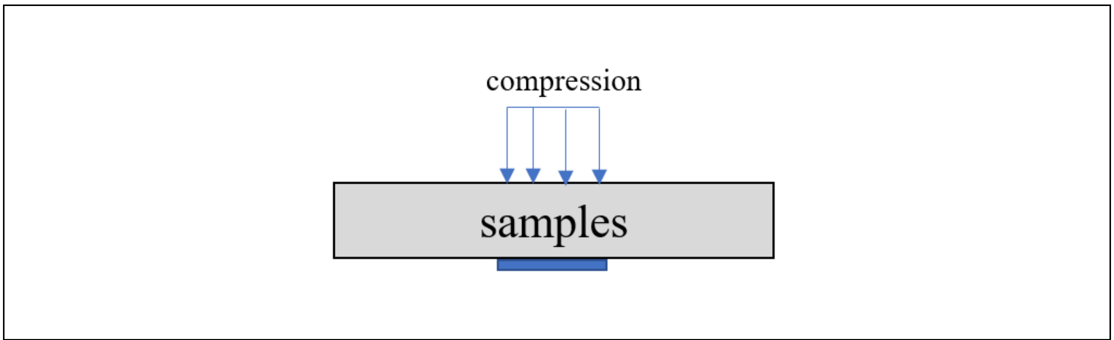
The result of three-point bending flexural test can be shown in Table 8.

Table 8: Result of Three-Point Bending Test

	σ_f (Mpa)	ε_f (mm/mm)	E_f (MPa)
Dry Opuka	11.5	0.00071	763
Wet Opuka	5.3	0.00132	546.18
Brick	2.7	0.00096	532.97

7.1.2 Compression Test

Samples of brick, dry opuka with moisture content of 0.39 percent and wet opuka with moisture content of 10.24 percent were placed on an iron plate for compression test until sample failure (see Figure 43).



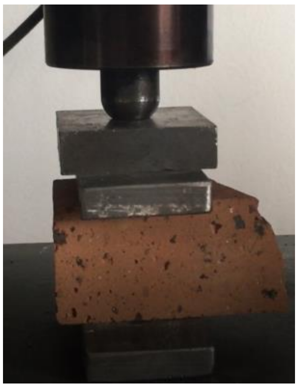
	
Dry Opuka (M.C. = 0.39 %)	Wet Opuka (M.C. = 10.24 %)
	
Brick	

Figure 43: Compression Test of uniaxial loads

The force and displacement graph can be shown in Figure 44.

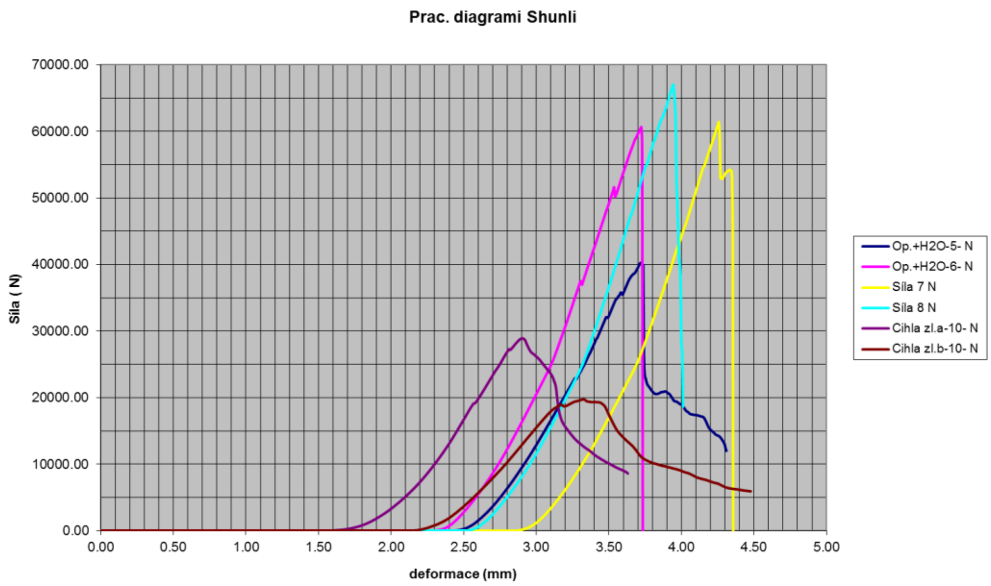


Figure 44: Force-Displacement Diagram for Dry Opuka, Wet Opuka and Brick

Based on measurements, the compressive stress σ_c, compressive strain ε_c and Young's modulus E_c of each sample were calculated by following formulas. The result can be shown in table 9.

$$\sigma_c = \frac{F}{bd} \quad (5)$$

$$\varepsilon_c = \frac{\Delta L}{L_0} \quad (6)$$

$$E_c = \frac{\sigma_c}{\varepsilon_c} \quad (7)$$

- F Maximum Compression Force
- L_0 Original Thickness (Height)
- ΔL Result of Displacement
- bd Compression Area

Table 9: Result of Compression Test

	σ_c (Mpa)	ε_c (mm/mm)	Average E_c (MPa)
Dry Opuka (a)	37.685	0.033	1189.92
Dry Opuka (b)	41.221	0.033	
Wet Opuka (a)	23.791	0.028	941.43
Wet Opuka (b)	34.3	0.033	
Brick (a)	17.257	0.028	532.79
Brick(b)	11.681	0.026	

7.2 Modelling of Columns on Main Façade

7.2.1 Pre-processing

Initially, based on the site visiting and visual inspection, the main deterioration of building Strahovská FARA occurred at columns of main façade. It is critical to determine whether the building 1 has static issue. Thus, the geometry of building 1 has been defined in the Site Survey (Section 5). The 2D geometry of the building 1 was created in AutoCAD (dwg) and imported in SCIA Engineering. The building 1 includes columns, arches, vaults, lateral and longitudinal load bearing walls, first and second floor walls, beams, interior walls and wall above arches. The roof section of building 1 is not considered in the static modeling. The distance between each of the beam in the model was defined as 1 meter. The general view of the structural model can be shown in Figure 45. The thickness of each structural elements on building 1 is based on the AutoCAD Plan of building 1 (see Section 5 and Table 10). The material properties were defined in section 7.1. Additionally, the boundary condition are applied after inputting the geometry and material properties. The bottom constrains of foundation were applied as rigid, and the constrains on lateral and longitudinal walls has rigid in Y, Rx and Rz directions (See Figure 46).

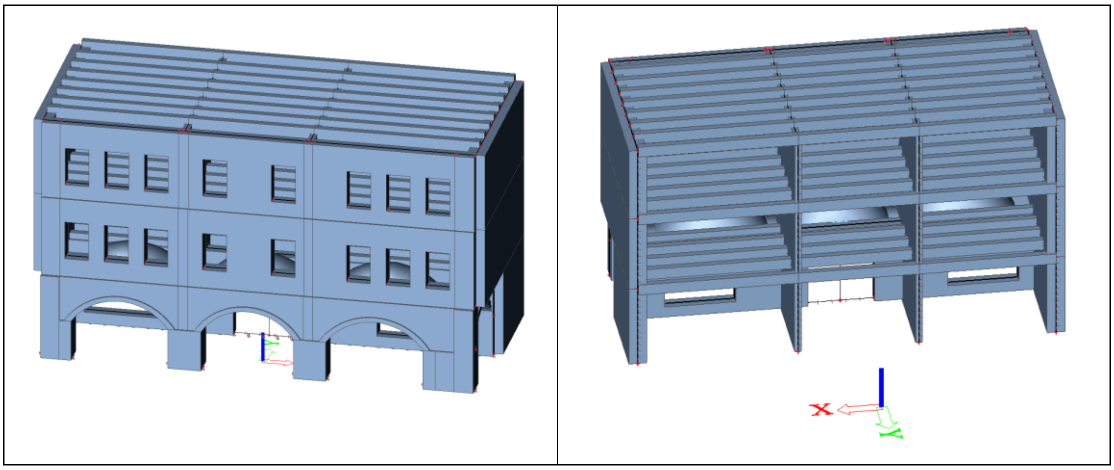


Figure 45: The General View of Building 1 Model

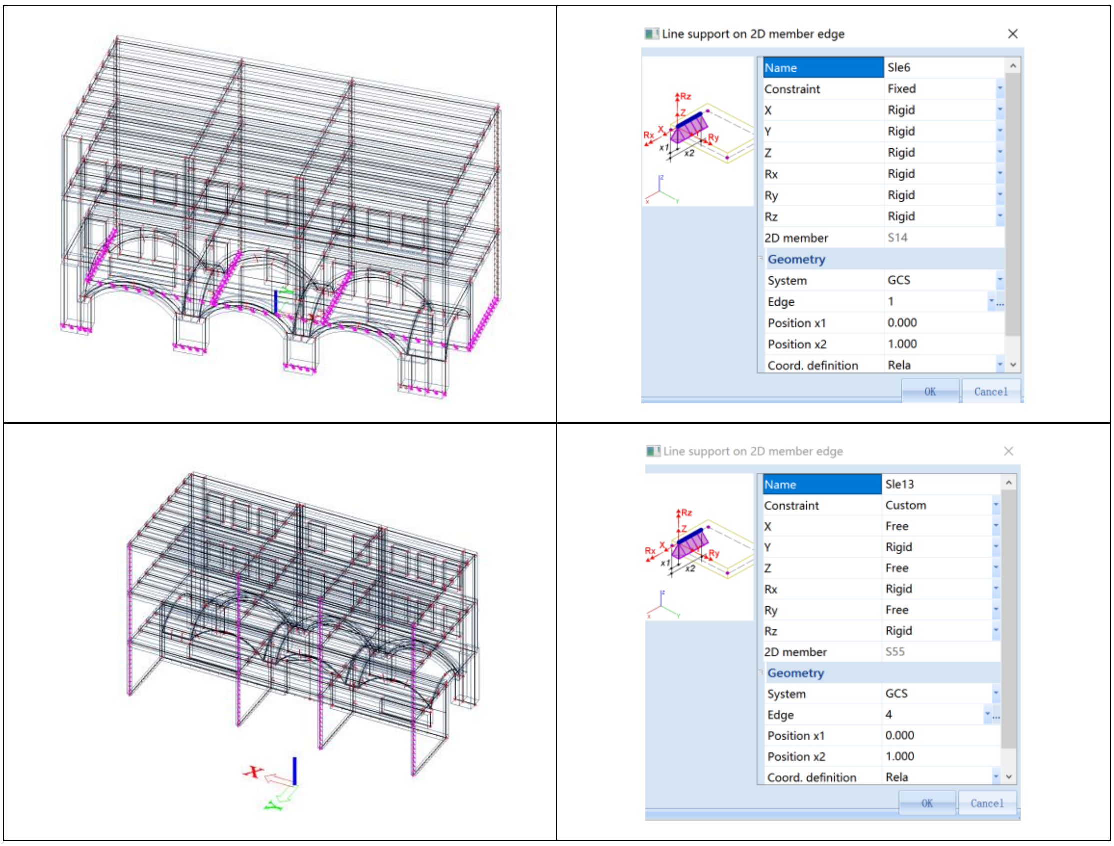


Figure 46: Boundary Condition of Modeling

Table 10: Thickness of Each Elements

Structural Elements	Thickness (mm)
Columns	1050
Arches	1050
Vault	300
Lateral Wall	800
Longitudinal Wall	800
First Floor Wall on Main Facade	750
Second Floor Wall on Main Facade	600
Wall above Arches	900
Interior Walls	300

Three types of loads have acted to model (see Figure 47). The first Load case is the self-weight of building 1 which defined by the program automatically. The second load case is the distributed permanent load of material which is 1.7 KN/m^2 applied on all beams from first floor to third floor of building 1. The permanent load material include 100mm thickness of slag(14KN/m^3), 12mm thickness of wood plate(6KN/m^3) and 10mm thickness of slab bolster (18 KN/m^3). The distributed uniform load of 15KN/m^3 was assumed acting on vaults. The third load case is the distributed live load which is 2KN/m^2. Based on the Eurocode 0, the load combination of ultimate limit state was applied on the model as shown as following.

Total Load = Load Case 1 ×1.35 + Load Case 2 ×1.35 + Load Case 3 ×1.5

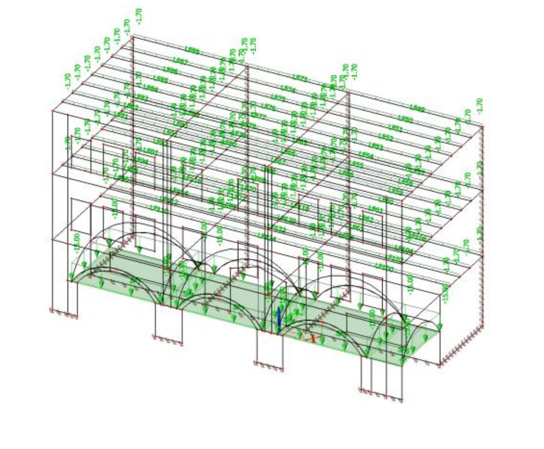
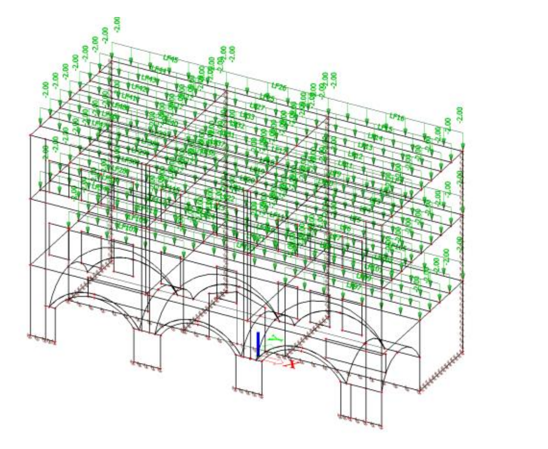
	
Load Case 2	Load Case 3

Figure 47: Load Cases of Model

The mesh was automatically generaged using quadrilateral meshe after the size of the element was manualy inputed as 0.7 (see Figure 48).

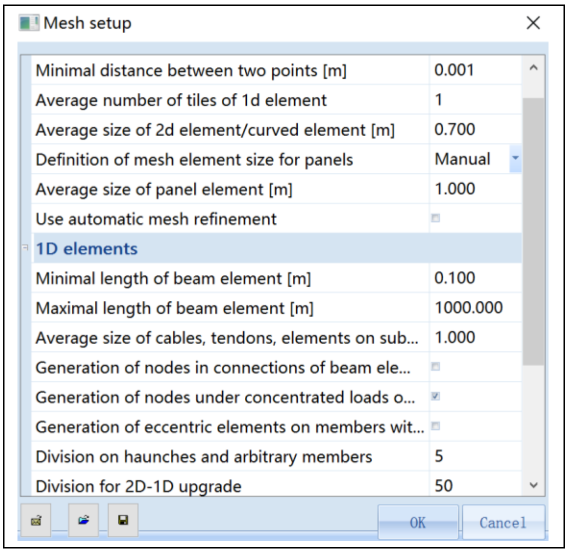


Figure 48: Mesh Generation

7.2.2 Post-Processing

a. Reaction on Supports

The reaction of supports can be shown in Figure 49. In the static view, the load of columns is in a reasonable level which would not bring damage-able effect to the building 1.

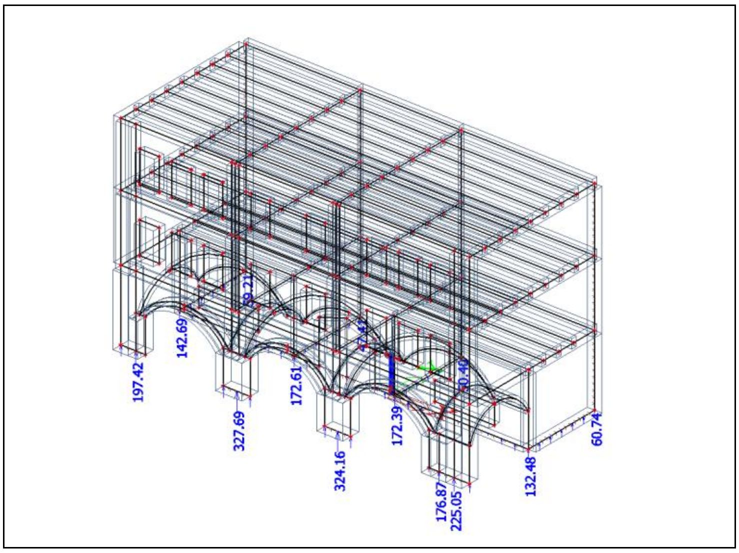
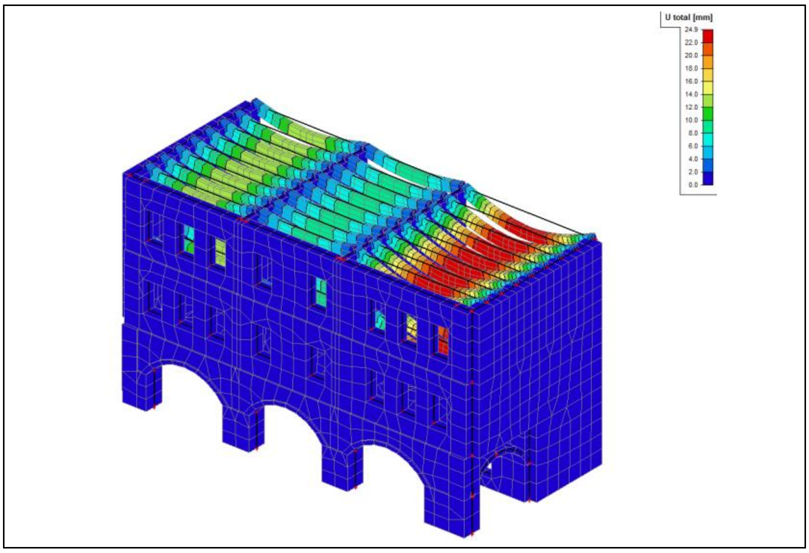


Figure 49: Reaction of Supports

b. 3D Displacement

The 3D displacement was shown in Figure 50. Based on the Figure #, Columns of main facade have not huge displacement, but right side beams from 1st floor to 3rd floor have maxmium displacement of 24.9mm.



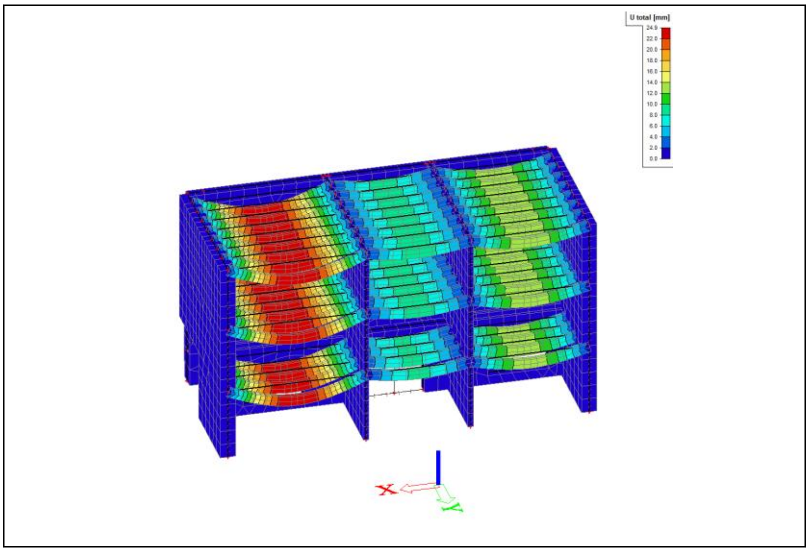


Figure 50: 3D Displacement

c. Structural Deformation

The structural deformation in x and y direction can be shown in Figure 51. Based on the result from Figure 51, the structure would not suffer huge deformation on y direction, but it would have huge deformation in x direction. Due to the original design of building, the deformation in x direction shows tendency of large deformaiton on arcade of main facade and second floor.

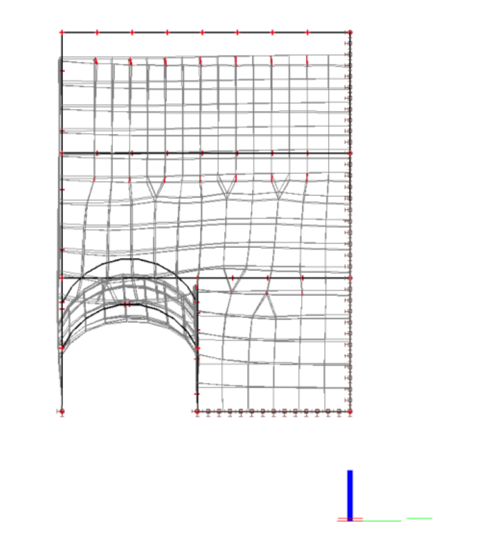
	
Deformation in Y direction	Deformation in X Direction

Figure 51: Structural Deformation in X and Y Direction

d. Conclusion of Static Modeling

After static model analysis, the building 1 of Strahovská FARA do not have huge static issue. In the static view, the building 1 of Strahovská FARA is at a safety level. In the long-term view, the second floor and arcade may have deformation problem. However, considering the building stands more than hundreds of years, it is not necessary to have static restoration to prevent its deformation problem immediately. Therefore, the building Strahovská FARA have main problem of moisture.

8. Intervention Proposal

The analysis of the cracking pattern observed in the historical building Strahovská FARA has pointed out that the damage present could mainly be produced by differential settlement, moisture issue and irregular geometry in some parts of building (see Section 6). The moisture problem includes rising damp and penetration damp, which weakens the strength of material in some parts of building. Furthermore, cracks and deformation noticed do not compromise the stability and global behavior of the structure. Therefore, based on the data collected in section 6 and 7, an immediate strengthening intervention for static is not necessary but moisture issue.

There is no denying the fact that the structure could suffer the problem of soil settlement. However, the building is statically safe after modeling analysis. Therefore, the strengthening of the foundation is not recommended immediately in this case as it would potentially cause further damage to the structure. It is still necessary to have plaster telltales test (sádrový terčík) or monitoring program. Considering some disadvantages of monitoring program such as high cost with long time consuming, the plaster telltales test has been immediately proposed in this section. The purpose of plaster telltales test can clarify some passive and active cracks in the building and proof the existence of soil settlement. On the other hand, the alternative plan could be monitoring program if the rehabilitation would not consider the time and cost issue. Nevertheless, if the active crack has been observed after using plaster telltales test, monitoring program is recommended to analyze further causes of crack, because it can present the practical reasons and factors of active crack. Whether the results obtained from the plaster telltales test or monitoring program, future interventions could be considered to avoid further damage to the structure.

The repair of crack proposed in the following section for building is aimed to recover the initial structural integrity and its aestheticity by repointing and injecting the large and medium size cracks due to the damage caused by differential soil settlement.

Interventions of moisture and columns are critical in this section, because it is aimed to avoid future damage caused by moisture problem. Some risk factors of column intervention have been discussed in the following section.

8.1 Intervention for Crack

8.1.1 Plaster Telltales

The movement of cracks can be studied by fixing dabs of plaster to the basic masonry or fixing glass telltales with epoxy resin [3]. The principle of the plaster telltales' method is that it would reveal immediately the continuing movement of crack, due to its fragility of plaster. Plaster have low tensile strength, and the scratch of crack pattern would form in plaster after placing it on the masonry, if the crack movement exits in the building. If the plaster would not show the scratch of crack pattern, it signifies that the crack movement is no longer exists in the testing period. If the testing period is long enough, the scratch of crack pattern would be relatively strong in the analyzing area. Normally, the observation period of plaster telltales is between 2 weeks to 1 month, but it depends on the crack activity of the building. The process of plaster includes 6 necessary steps [17].

1. Indicating analyzing cracks and measuring the width and length of cracks.
2. Cleaning dust and incoherent parts inside and surrounding of cracks.
3. Moistening inside and surrounding of analyzing cracks. Placing dense plaster on cracks with approximately dimension of 80x160mm to 100x200mm with thickness of 10 mm (see Figure 52). It depends on the real situation of crack width and length.

Figure 52: Plaster Placement in Masonry [2]

4. Indicating the target identification number of testing cracks and recording the testing dates.
5. Making initial record (taking pictures).
6. Observation after 2 to 4 weeks (weekly observation is recommended).

In the case of building Strahovská FARA, 4 cracks in different parts of building should be tested, which are C1, C3, D1 in lower position and F1 (see Section 6 - Static Inspection and Diagnosis of Cracks). 2 weeks observation period is necessary in this case, and 1 month is recommended. All test material should be reversible and removable.

8.1.2 Monitoring Program

Long term monitoring devices will be used throughout building Strahovská FARA to aid in confirming the previous results from Plaster Telltales Test, if cracks are active. Additionally, to ensure little visual impact and system efficiency, a wireless network is proposed and recommended that can manage the data from all sensors. For this purpose, the iNova Network Structure from NovaTest provides acts as a good platform, and it can provide communication between the sensors and the data center (See Figure 53). The Gateway/GPRS wireless iNova datalogger is added to the network for the acquisition and storage of monitoring data, which allow users to analyze and download the data remotely. The iNova Data Manager and iNova Smart Platform acquires, stores, displays, and exports all data on a Windows, Mac, or Linux computer system. A router is not required for this system if the range of connection is 200m for the iCloud Gateway.

Figure 53: The iNova Gateway Cloud GPRS and iNova Data Manager

To determine whether the active cracks are due to cyclic thermal action, soil settlement, or other static reasons, crack gauges will be placed throughout the exterior and interior of the structure. The systems to be used are the iNova Transducers, which are configured to the iCloud Gateway GPRS (See Figure 54).

Figure 54: iNova Transducer

The acquisition interface is 90 x 90 x 60.5mm, powered by batteries. The stroke of the gauges is 25mm and the resolution is 0.000003 mm with a tolerance of ± 0.15%. The system also measures temperature with a range of -40°C to +125°C (tolerance ± 0.3°C and resolution 0.01°C) and air relative humidity of 0-100% (tolerance ± 2.0% RH and resolution ± 0.04%). The displacement and temperature data will be collected and measured for at least 2 years (recommended 4 years) with a monitoring and transmission frequency of 10min. The average lifetime of the system is approximately 2 years, thus requiring the batteries to be changed midway through the monitoring program if monitoring period is 4 years.

8.1.3 Repointing and Injection

Repointing and injection is proposed to repair all cracks mentioned in section 6 - Static Inspection and Diagnosis of Cracks, in order to recover the structural stability of building Strahovská FARA. The purpose of this crack treatment is to stop the movement of the building. Scaffolding with platform should be applied for this intervention. In order to enhance the integrity of material, it is very important to characterize the original mortar to ensure compatibility between new and original materials from physical, chemical and mechanical point of view. If the repointing or injecting mortar could not match the original mortar in the building for some unexpected reasons, mortar usage should satisfy following requirements [18].

1. Repointing mortar should be strong enough to meet any structural requirements, while not being so strong as to inhibit movement of the masonry [18].
2. It should be weathertight [18].
3. It should match the color and texture of the original mortar [18].

All medium and large cracks on the main façade (around window area), back-side of building 1 and backyard, repointing should be applied. Before repointing, old mortar should be professionally removed by using air spray or soft brushes, the joints moistened with a hose and sprinkling nozzle or with a brush [18]. The purpose of pre-moistening is that it can remove small or loose particle in the joints, improve the bonding ability between old masonry and new mortar and avoid large and fast water absorption of masonry. Additionally, the intervention of cracks on the wall is recommended to perform injection on both sides of the damaged masonry wall, in order to improve its effectiveness of intervention. In the case of vaults, the injection should be carried out starting from the intrados and filling the cracks towards and upwards by pressure. Furthermore, all material and techniques used in the historical building should be reversible and removable.

8.1.4 Active Crack Intervention

If some active cracks have been observed by using Plaster Telltales Test, it is important to do the detail monitoring, in order to know the reasons of crack movements professionally. After that, two intervention options are recommended as following:

1. Periodically inspection should be applied until the repair is necessary.
2. After proper monitoring professional intervention plans should be done (economical factor considered).

8.2 Intervention for Columns Remediation

According to the section 6 (Inspection and Diagnosis of damage and decay), the analysis of load-bearing columns on the main façade of Strahovská FARA have pointed out that the present damage was produced by moisture problems. Based on numerical model analysis in section 7.2 and the information collected above, columns do not compromise the stability and global behavior of structure immediately, but it may cause future static problems. Taking the Column A as an example, moisture can mainly infiltrate column in 3 directions (See Figure 55). In order to reduce the effect of moisture problem on columns, an immediate treatment of column replacement is proposed in this section. This treatment of column replacement has been considered intervention procedures and experience from neighbor building (Pohorelec 112, Praha) [19].

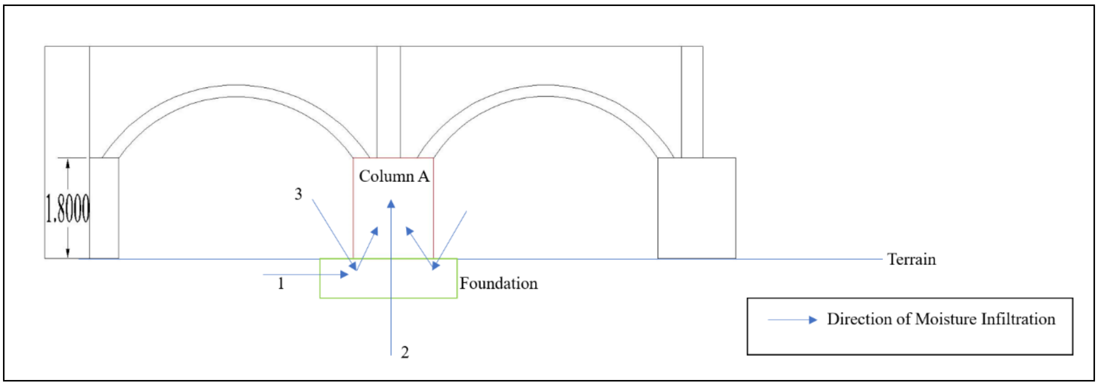


Figure 55: Moisture Infiltration Directions

The main risk factor of column replacement in this case is pre-stressing. When the old column is taken out, the distribution of forces on main façade is changed. Since the new column is put back, it cannot usually be prestressed. Thus, the column replacement should have local readjustment of the stressing before new column carrying its load.

The procedure to column replacement will be based on the following phases:

1. Before the column replacement, temporary work of wooden shoring and steel support should be carried out. The wooden shoring and steel support for lifting should be considered as the same form of neighbouring building (Pohorelec 112, Praha), but it should use wider and longer dimension in horizontal and vertical direction, due to the long span and low raise of arches in building Strahovská FARA (See Figure 56). The dimension of wooden cradling should be based on the dimension of span and rise of arches in building Strahovská FARA.

Figure 56: Wooden Support to Secure Structure of Building in Pohorelec 112, Praha [19]

2. Due to the slop of the terrain, flat concrete slab should be placed in front of replacing column (See Figure 57). The length of each concrete slab is based on the width of each columns.

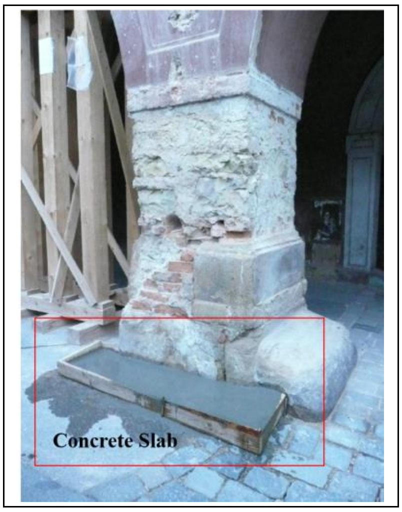


Figure 57: Concrete Slab Placement for Building in Pohorelec 112, Praha [19]

3. Above the concrete slab, steel shoring should be constructed, in order to provide further support to arch rib (See Figure 58).

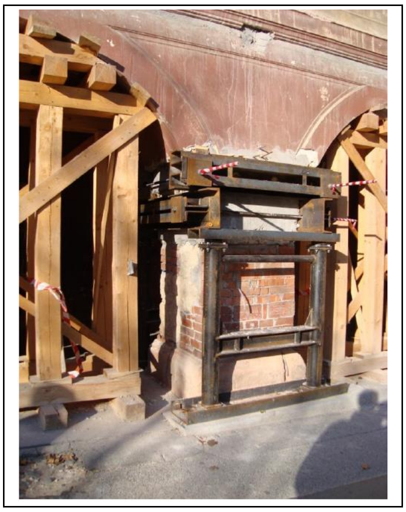


Figure 58: Steel Support for Lifting Building in Pohorelec 112, Praha [19]

4. Old Column of building Strahovská FARA should be taken out 1.8 meter from terrain to arch rib (See Figure 59). Columns should be replaced individually in different time, and the replacement order should start from column A to Column D.

After each column replacement, more than 2 weeks settlement is recommended. Column replacement material should use bricks and mortar with certain characteristics. In plinth area, it is necessary to apply preparatory mortar and special plaster to protect masonry against splashing water. Above this plinth area, plaster which allow masonry breathing （Putty Reinkalkstuck from Remmers） is necessary to apply.

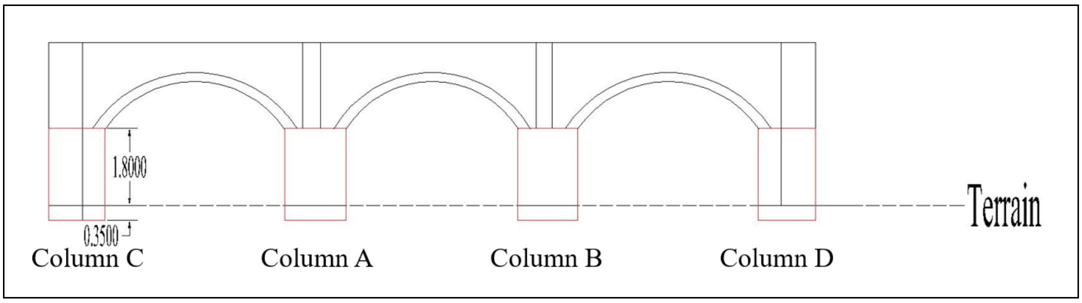


Figure 59: Column Replacement

5. Due to the situation of moisture infiltration described above, two intervention plans have been proposed. Both methods can directly avoid shear and dampness problem, but second method is strongly recommended. For the first method, DPC with sandblasting surface should be placed under the bottom part of new column (See Figure 60).

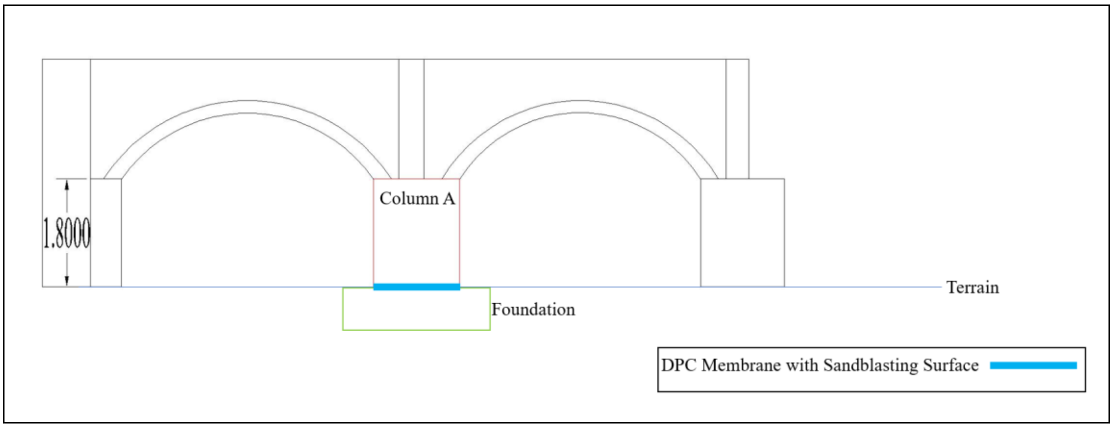


Figure 60: Intervention of DPC with Sandblasting Surface

On the other hand, due to the large load of new column in horizontal joint, alternative and effective method is proposed. In this case, DPC with shear connector should be applied at bottom part of column (See Figure 61). Epoxy resin is necessary to seal the shear connector.

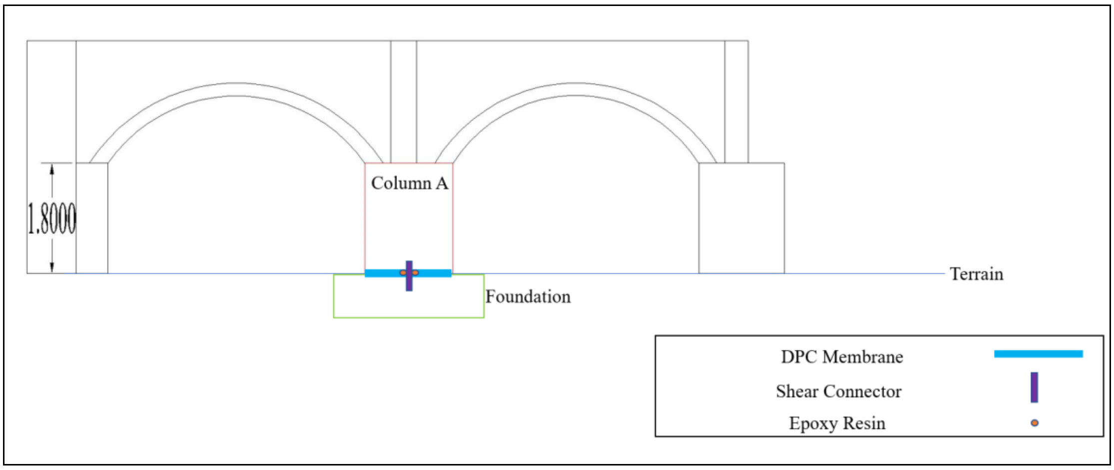


Figure 61: DPC with Shear Connector and Epoxy

8.3 Intervention for Moisture Problems

Based on the section 6 (Inspection and Diagnosis of damage and decay), back-side of building 1, building 2,3 and walls suffer from combination problem with rising damp and splashing water. In order to reduce unfavourable effect of dampness, inserting DPC as protection against rising damp and applying of preparatory mortar and plaster as protection of splashing water are proposed. The main risk factor of inserting DPC is the bridging. Taking masonry wall as an example, moisture can soak upwards through porous material that spans the DPC membrane (See Figure 62). Thus, water-repellent or hydrophobization material should be applied to plaster, in order to stop rising damp.

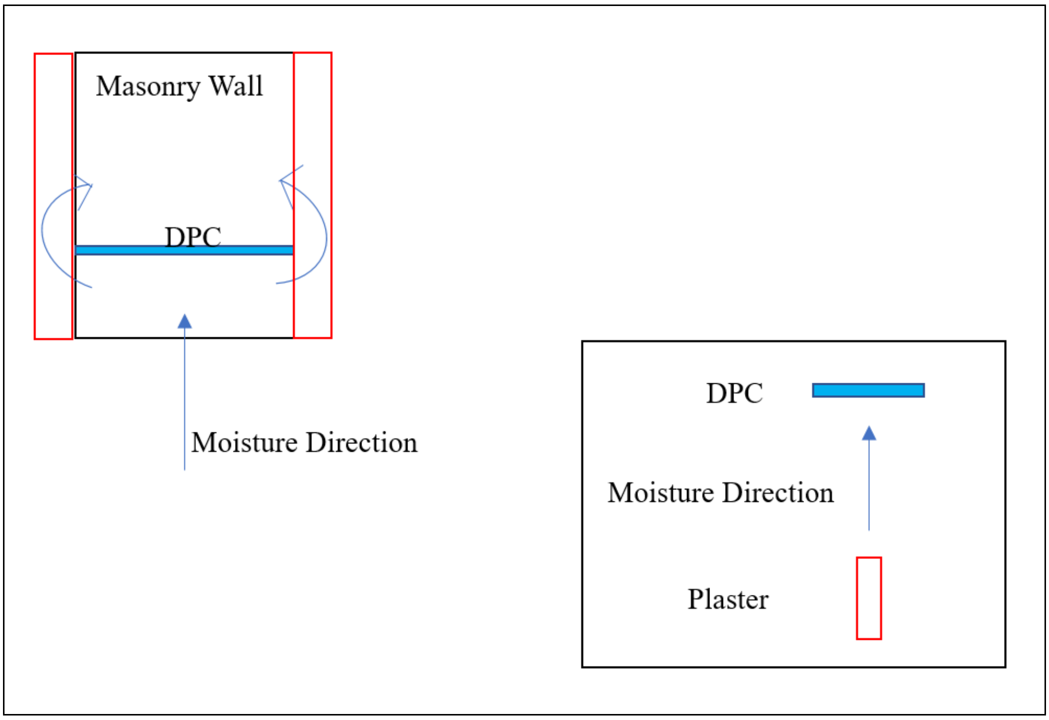


Figure 62: DPC Bridging on Masonry Wall

In practice, several dampness rehabilitation methods exist. Each method has its own advantages and disadvantages, so the selection of suitable method in the case of building Strahovská FARA should be based on detailed moisture survey which include the description of moisture regime of the building, which is verified by laboratory analysis (See Table 11).

Table 11: Rehabilitation methods for Dampness

Dampness Rehabilitation Method	Description	Disadvantages for Building Strahovská FARA
Air Systems	To install air gaps or air vents to walls, floor and interior of building	It cannot apply for columns and staircase of building
Retrofit DPC (Mechanical Method)	To retrofitting DPC to gap done by sawing or driving of metallic sheets	It requires horizontal mortar joints
Electroosmotic Method	Removing moisture by using active electroosmosis	The efficiency of method depends on many factors, such as porous material, salt content, pH values…etc.

Except those methods written above, chemical-injection DPC can efficiently remove most of the dampness problems in building Strahovská FARA. The principle of this method is to create a water-repellent zone at the base of masonry by inserting appropriate fluids into a series of pre-drilled holes [20]. This method could be applied by two technologies, infusion and high-pressure chemical injection (See Figure 63). In this case, the way of high-pressure chemical injection is recommended, due to high content of moisture at in masonry.

	
Infusion	High-Pressure Chemical Injection

Figure 63: Two Technologies

Procedures of High-Pressure Chemical Injection is listed as following:

1. Drilling several holes in diameter of 10 to 15 millimeters in a line along the mortar joint of repairing area. Holes should be drilled within about 50 millimeters of the other side of masonry [20].
2. The general process of this method can be shown in Figure 64.

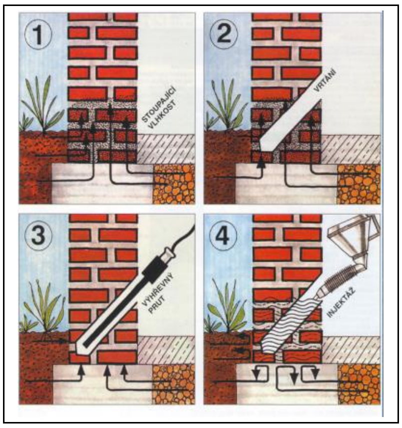


Figure 64: General Process of Chemical Injection DPC

On the other hand, due to most of the deterioration of building Strahovská FARA having problem of water splashing, it is necessary to apply remedial plaster with preparatory mortar at plinth part of damaged area. This treatment can easily and quickly vaporize excessive moisture, due to the porous structure of plaster. This treatment procedure is listed as following:

1. Removing all solid previous mortar in the joints or other places on the mixed masonry
2. Applying a adequate layer of preparatory mortar (Vorspritzmörtel preparatory mortar from Remmers is recommended). The characteristics of this preparatory mortar and can be shown in Figure 65.

Colour:	grey
Bulk density:	approx. 1.7 kg/dm³
Working time:	approx. 60 minutes
Compressive strength:	CS IV
Water penetration depth:	after 1 hour > 5 mm
Reaction to fire (DIN EN 998-1):	Euro class A 1

Figure 65: Characteristics of Vorspritzmörtel Preparatory Mortar from Remmers

3. Applying remedial plaster with additional natural hydraulic metakaolinit (Putty Reinkalkstuck from Remmers is recommended).

8.3.1 Detail Interventions on Lateral Wall and Staircases

Due to situation (difficulty applying of moisture interventions) on lateral wall of building Strahovská FARA, the treatment of lime plaster is recommended. This treatment has not long-time durability, so it should be replaced frequently. Additionally, it is necessary to check other side of lateral wall by structural survey of neighbouring building (See Section 6.1).

On the other hand, except applying moisture interventions on staircase of building 2, it is necessary to apply roof covering and drainage pipe for discharging water falling from roof covering (See Figure 66). This drainage pipe should be connected with existing drainage pipe.

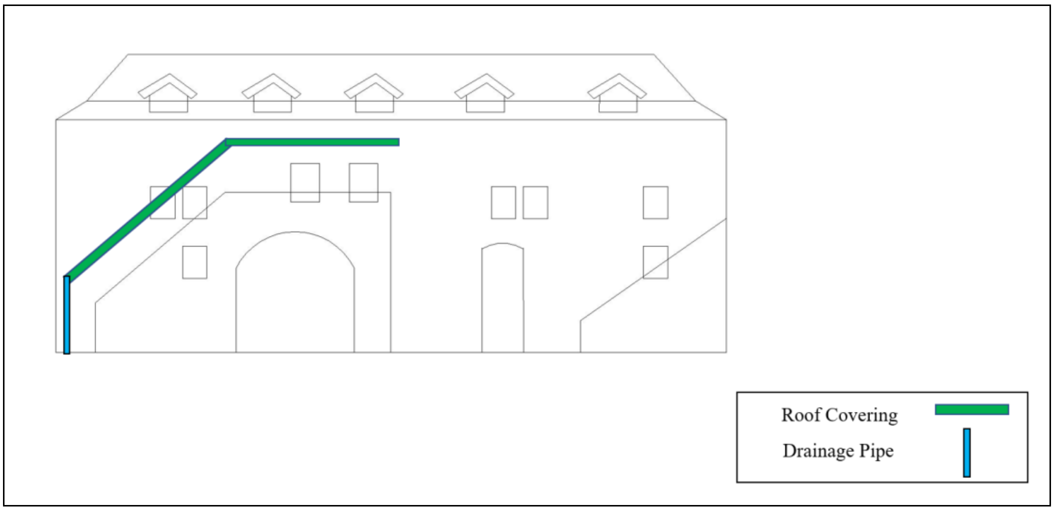


Figure 66: Intervention of Roof Covering

For the interior of staircase, it is necessary to replace wooden stairs by stone. Stone stairs should be inserted into both sides of masonry (See Figure 67). Meanwhile, for the interior wall of staircase at building 2, hydrophobization material is necessary to apply above 50 centimeters height of each stone stair.

Figure 67: Detail Intervention for Interior wall of Staircase

8.4 Intervention for Salt Crystallization and Drainage Pipe Leaking

8.4.1 Intervention of Salt Crystallization

According to the Section 6, part of masonry in the building 3 contains high amount of salt contamination, which can predominately the moisture of building material and affect the strength of masonry wall as well. Thus, cleaning all salty contamination areas by using the desalination material is proposed. For the desalination, removable poultices will be applied in this section. This cleaning method represents the utilization of minimum intervention and less aggressive techniques. The poultice used for salt cleaning is based on cellulose fibers or on mixes of cellulose, clay and sand or light aggregates [21]. This salt removing process should be repeated professionally in an adequate amount of times until minimum salt contents. After removing salt contamination, lime mortar can be applied on masonry, in order to assure good contacts in all points.

8.4.2 Intervention of Drainage Pipe Leaking on Main Façade

During the survey, several damaged drainage pipes were found, it should be checked and repair as soon as possible. For the damaged area, it is necessary to repair by using the same mortar and plaster mentioned in section 8.3.

9. Maintenance Plan

The routine intervention and upkeep to follow are described in this section. The desirable standard of maintenance depends upon the intensity of the climatic and other agents of decay, as well as upon the needs of the users [3]. In this section, moisture controlling and column stability checking are considered.

9.1 Moisture Controlling

In order to ensure a good quality of structure, moisture controlling has been proposed. An regular inspection procedure should be carried out at least twice a year, in order to determine the effectiveness of the maintenance plan and to make appropriate changes.

1. Extraction manually of all the plants and spider web on the arcade observed on building Strahovská FARA.
2. Keep water away from building by checking the roof flashing and gutters.
3. Check all drainage system during the heavy raining period. It is necessary to maintain whether the drainage system of entire building has damages.

9.2 Stability Checking

Due to the moisture problem and proposed intervention on columns in section 8, it is necessary to do a periodical inspection every 2 years of the stability of columns on main facade caused by moisture effect. The material of moisture content and crack visual survy is also recommended during the inspection. Meanwhile, visual inspection should be conducted to determine cracks on the wall and vaults. Therefore, a professional crack width measurement is recommended, in order to collect information of crack activity.

10. Conclusion

The principle of this thesis describes the necessity of individual rehabilitation methods and procedures. Meanwhile, the risk factor of interventions and the limitations of their usability with regards to the requirements for the functional reliability and durability of the building have discussed. The protection of building Strahovská FARA from moisture and water is the most critical measures which can ensure the service life and serviceability of the building, as well as the reliability of the material.

In order to achieve this principle, the historical building Strahovská FARA was investigated through visual inspection to indicate damage, decay, and cracks currently presented in the structure. These failures were diagnosed and analyzed. Failures and decay is primarily cost by moisture, missing DPC and climatic agents. The crack formation is done, due to the mechanical deterioration and soil movement. In order to understand deterioration of building, several laboratory tests have been done. A monitoring program was introduced to collect data regarding the opening of the active cracks to confirm whether the prediction made in diagnosis were valid. In order to check static problem of building, an numerical model has been built and analyzed for main façade and main part of building 1. On the other hand, to ensure that the building does not experience any further damages, a maintenance plan was formulated. In the end, the building Strahovská FARA is in a statically safe condition, but interventions of repairing cracks, column replacement and interventions of moisture problem written in previous section are highly recommended.

11. Reference

[1] ICOMOS- International Council On Monuments and Sites,《International Charter for The Conservation and Restoration of Monuments and Sites---The Venice Charter 1964》, Adopted by ICOMOS IN 1965

[2] Richard Oxley, 《Survey and Repair of Traditional Builidngs-A Sustainable Approach》,PP. 4; 139-142, Donhead Publishing, Donhead St Mary Shaftesbury Dorset Britain, 2003

[3] Bernard M. Feilden, Kt, CBE, D Univ, D Litt, FSA, FRSA, AA Dipl(Hons), FRIBA, Director Emeritus, 《Conservation of Historic Buildings(Third Edition)》, PP.41-61; 235; 363, International Centre for The Study of The Preservation and The Restoration of Cultural Property(ICCROM), Rome

[4] Andrew Beattie, 《Prague》, PP. 6; 11, Interlink Cultural Guide, INTERLINK BOOKS, Interlink Publishing Group Inc., United States of America, 2014

[5] Justin Hettinga, "Structural Analysis of the Roof of St Anne's Church", PP.8, Advanced Masters in Structural Analysis of Monuments and Historical Constructions Master Thesis, Erasmus Mundus 2009, Czech Republic

[6] History of Strahov Monastery. Retrieved May 15, 2017 <https://www.strahovskyklaster.cz/en/history>

[7] Dorcadion Team (Ed.), (2015, March 25), House "At the Golden Lion". Retrieved May 15, 2017 <http://www.waymarking.com/waymarks/WMNJVB_House_At_the_Golden_Lion_Dum_U_Zlatho_lva_Pohorelec_Prague>

[8] Athena Review, 《Introduction: Flowering of the Gothic》，PP.20-21, Vol.4. No.2 of Athena Review, Athena Publication. Inc

[9] Slavíková, M., Krejčí, F., Žemlička, J., Pech, M., Kotlík, P., & Jakůbek, J. (2012). "X-ray radiography and tomography for monitoring the penetration depth of consolidants in Opuka – the building stone of Prague monuments". *Journal of Cultural Heritage, 13*(4), 357-364. doi: 10.1016/j.culher.2012.01.010

[10] Ing. Lumir Caithaml-GEO Luca geotechnicka Kancelar, "Geotechnicky Pruzkum Zakladu Pilire V Podloubi" (Pohorelec Fara C.P. 113 Praha 1-Hradcany), 2016, Requested(Objednatel): Kralovska Kanonie Premonstratu na Strahove, ICO:16947401, Brevnov; Praha 6 Czech Republic

[11] Ing. Vaclav Jandacek, "Geotechnicky Pruzkum Zalozeni Jednoho z Piliru

Podloubi(Pohorelec Fara C.P. 113 Praha 1-Hradcany), 2016", Requested(Objednatel): Kralovska Kanonie Premonstratu na Strahove, Brevnov; Praha 6 Czech Republic

[12] Prof. Sergio H.P. Cavalaro and Miren Etxeberria, "Consolidation of Degraded Brick and Masonry", Technical University of Catalonia(UPC), 2017

[13] Prof. Sergio H.P. Cavalaro and Miren Etxeberria, "Decay by Soluble Salts", Technical University of Catalonia(UPC), 2017

[14] Malcolm Hollis, Building Pathologist, Chartered Building, Surveryor and Professor Building Surveying, Charles Gibson, MA (Oxon) of Lincoln's Inn a Circuit Judge, Surveying Building(Fifth Edition), Published by the Royal Institution of Chartered Surveyors (RICS), Surveyor Court, Westwood Business Park, Coventry CV4 8JE, UK

[15] Dechen Tshering, "Structural Survey of Historical Building. Church of St Lawrence (Sv. Vavrinec)", Advanced Master in Structural Analysis of Monuments and Historical Constructions, Erasmus Mundus, SAHC, 2009, Czech Republic Prague

[16] Allen, D., Cooksey, C., & Tsai, B, Spectrophotometry, 2010, October 5, Retrieved <http://www.nist.gov/pml/div685/grp03/spectrophotometry.cfm>

[17] STATIK-PROJEKTANT, "Sledování trhlin ve stěnách pomocí sádrových terčů", 2012, June 18, Retrieved June 20, 2017, <http://statik.webnode.cz/news/sledovani-trhlin-ve-stenach-pomoci-sadrovych-tercu/>

[18] "Repointing Masonry Walls", Section 6.2, Resource Information From The International Masonry Institute, Technology Brief, October 2002, <http://imiweb.org/wp-content/uploads/2015/10/06.02-Repointing-Masonry-Walls.pdf>

[19] Ana Martins, Bruno Fernandes, Luis Dias, Intervention of Column Replacement at Pohorelec 112 Praha, Department of Building Structures Czech Technical University in Prague Faculty of Civil Engineering, December 2010

[20] Thomas Unger; Ing. CSc. Eva Burgetova, 《Seminar Work Building Structure 6》, , Department of Building Structures Czech Technical University in Prague Faculty of Civil Engineering, 26th November 2009

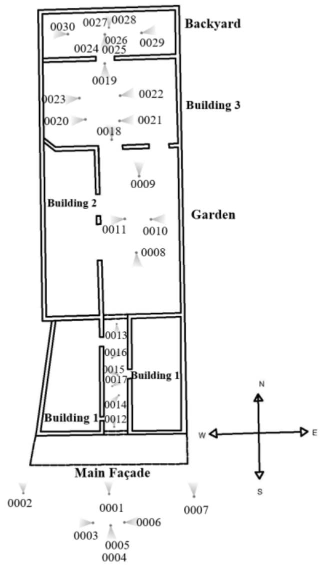
[21] J. M. J. R. Á. G. J. a. C. V. Garabito, 《Methods for physical, chemical and biological cleaning of historic stone-masonry monuments》, *Informes de la Construcción,* vol. 65, nº 531, pp. 367 - 38, 2013.

[22] Prof. Luis F. Ramos and Paulo B. Lourenco, "SA4: Inspection and Diagnosis-Visual Inspection Techniques", Technical University of Catalonia(UPC), 2017]

APPENDIX

Appendix A: Photographical Survey

Round View of the Building Pohořelec



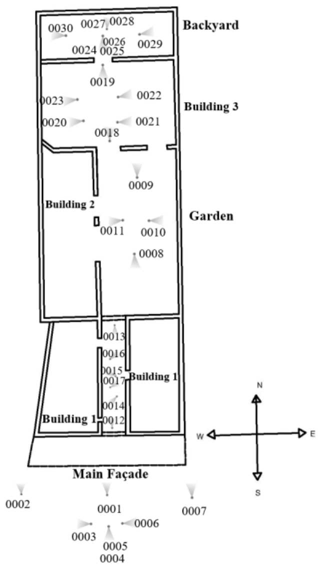
0001 Main Façade of Building Pohořelec

0002 Left Neighbor Building A

0003 Left View of Building Pohořelec

	
0004 Right Back View of Building Pohořelec	0005 Left Back View of Building Pohořelec
	
0006 Right View of Building Pohořelec	0007 Right Neighbor Building B

General View of Building Pohořelec



Exterior View

0008 Back side of Building 1	0009 Front Side of Building 3
	
0010 Wall Side of Garden	0011 Lateral Side of Building 2

Interior View of Building 1	
	
0012 Gardern View of Building 1	0013 Door View of Building 1
	
0014 Neighbor Buildng A Side of Building 1	0015 Neighbor Buildng A Side of Building 1
	
0016 Neighbor Buildng B Side of Building 1	0017 Neighbor Buildng B Side of Building 1
Interior View of Building 3	
	

0018 Backyard Side of Building 3	0019 Garden View Side of Building 3
	
0020 Neighbor Buildng A Side of Building 3	0021 Neighbor Buildng B Side of Building 3

	
0022 Neighbor Buildng A Side of Building 3	0023 Neighbor Buildng B Side of Building 3
Backyard View	
	
0024 Back Side of Building 3	0025 Back Side of Building 3
	
0026 Back Side of Building 3	0027 Back Side of Backyard

	
0028 Back Side of Backyard	0029 Neighbor Buildng B Side of Building 3

0030 Neighbor Buildng A Side of Building 3

Appendix B: Causes of Decay

1. Gravity Causes Building to fall down [3]

Types	Causes
External Causes of Decay	The sun produces light with ultraviolet and heat radiation
Climate Causes of Decay	1. Seasonal temperature changes 2. Daily temperature changes 3. Wind 4. Precipitation of rain and snow 5. Ice and frost 6. Groundwater and moisture in soil dust
Biological and Botanical Causes	1. Animals 2. Birds 3. Insects 4. Trees and plants 5. Fungi, molds, lichens 6. Bacteria
Natural Disasters	1. Tectonics 2. Earthquakes 3. Tidal waves 4. Floods 5. Landslides 6. Avalanches 7. Volcanic eruptions 8. Exceptional winds 9. Wild fire

2. Causes and Diagnosis of Dampness [15]

Type of Dampness	Causes
Rising Damp	1. Absence or Failure of a damp-proof course 2. Hard surface around the outside base of a wall which will deny evaporation of moisture from the wall surface 3. High water table 4. Porous substrate 5. Cement rich mortars, low absorption bricks 6. Underground plumbing leaks
Penetrating Damp	1. Precipitation (rainwater, snow, sleet, hail and fog)-gravity pull of precipitation vertically through weak points in the roof or other horizontal surface 2. Leaking or overflowing external plumbing goods 3. External water surcharge(flooding) caused by blockage of drainage or gullies 4. Failure of render or other surface finishes – moisture forced in through cracks and gaps in wall by lateral winds and higher external pressures 5. The stone or brick has become excessively porous 6. Pointing or external render is, failing or inappropriate
Condensation	1. Lack of ventilation which leads to building up of moisture vapor in recesses and external corners which are liable to be those most exposed to heat loss 2. If building is let unoccupied, particularly in winter, local condensation of stagnant air when the temperature drops can produce suitable conditions for such fungal growth as molds on walls and ceilings and dry rot in the structural timber 3. Damp wall through penetrating or rising dampness 4. Soluble salts deposited on wall – warm air inside the building dry out the moisture on one side of the wall and these salts attract some amount of dampness from the air and they also form a barrier to the evaporation of water through the wall surface

Appendix C: Crack Analysis Guidelines [22]

Classification	Recommended Ambient	Maximum Width
Very thin	Impermeable	0.1 mm
Thin	External Exposition	0.2 mm
Medium	Humid Internal Exposition	0.3 mm
Large	Dry External Exposition	0.4 mm
Severe	Unacceptable	>0.4 mm