Historical Monuments of Mtskheta, C 708

The present folder contains:


   Annex 1: Strategy for World Heritage Stare Program


   Annex 3: Report of the project Conservation of Armaztsikhe Archaeological Site


Prepared by:

The National Agency for Cultural Heritage Preservation of Georgia

5, Tabukashvili str, Tbilisi, 0105, Georgia
www.heritagesites.ge
Dear Mr. Kishore Rao,

In conformity with the decision 37 COM 7A.33 of the 37th session of the World Heritage Committee I would like to present you the State of Conservation Report for the Historical Monuments of Mtskheta. The report is complemented with the project documentation implemented on Mtskheta World Heritage Site by the National Agency for Cultural Heritage Preservation in 2013.

Furthermore, I have a pleasure to present for your consideration the draft World Heritage State Programme, prepared in conformity with the World Heritage Committee decisions 36COM 7A.31, 37COM 7A.33 and based on the Strategic Objectives for the Implementation of the World Heritage Convention (5Cs).

We would highly appreciate having the comments and advices from the World Heritage Centre and Advisory Bodies on the proposed draft document. We are convinced that the State Programme will become an effective instrument for implementation of the World Heritage Convention at the national level in Georgia as well as the platform for further strengthening the cooperation with the World Heritage Centre.

In addition, I would like to welcome the World Heritage Centre Initiation to create the online platform for the State of Conservation Reports of the World Heritage Sites. It would increase the awareness of the visibility of the World Heritage Convention. Therefore, with reference to the Circular Letter of 2 December 2013 (Ref. CL/WHC-13/23) from the Chairperson of the World Heritage Committee, the State Party gives its consent to upload in public access State of Conservation Reports for the World Heritage Sites of Georgia on the web-site of the World Heritage Centre, particularly on the newly established State of Conservation Information System (http://whc.unesco.org/en/soc).

We are open to provide further information on any issues related to the mentioned World Heritage Site.
Please, accept the assurance of my highest consideration,

Annex 2: Draft World Heritage State Program of Georgia

First Deputy Minister

Marine Mizandari
Historical Monuments of Mtskheta World Heritage Site
State of Conservation Report

National Agency for Cultural Heritage Preservation of Georgia

January 2014

This Report on the State of Conservation of the Historical Monuments of Mtskheta (C708, Georgia) has been prepared following the request of the World Heritage Centre (Ref: 37 COM 7A.33) so that the World Heritage Committee may examine the state of conservation of the property at its 38th session in Doha, Qatar in 2014.
1. INTRODUCTION

<table>
<thead>
<tr>
<th>State Party</th>
<th>Name of the Property</th>
<th>Date of Inscription</th>
<th>Criteria</th>
<th>Organization responsible for the preparation of the report</th>
<th>Date of Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>Historical Monuments of Mtshketa</td>
<td>1994</td>
<td>C (iii, iv)</td>
<td>National Agency for Cultural Heritage Preservation of Georgia</td>
<td>2014</td>
</tr>
</tbody>
</table>

2. SIGNATURE ON BEHALF OF STATE PARTY

Marine Mizandari

First Deputy Minister of Culture and Monuments Protection of Georgia

3. STATEMENT OF SIGNIFICANCE

AS PROVIDED BY STATE PARTY IN THE NOMINATION DOSSIER

“City-museum, architectural reserve, Mtshketa is a multi-layered monument, testifying to the great scope of building activity and high culture of the country. Preserved architectural monuments and unearthed archaeological material testify to the high artistic value of building and minor arts in various epochs, beginning from the 2nd mill. B.C. to today. The architectural monuments of Mtshketa, being stage-making in the development of Georgian architecture are at the same time extremely significant for the study of the medieval architecture of the whole Christendom. Besides they are striking examples of the unity of architecture with the surrounding landscape. Of special value from the artistic and historical points of view are the monuments of monumental painting (mosaic floor in “Dionysius Maison” in Dzalisa, 2nd c. A.D.) and metalwork (goldsmithery) discovered in Mtshketa. Special place in Semitic epigraphic is occupied by Armazi inscriptions, giving vast valuable data for the study of the written language in general and making it possible to deal with the origin of Georgian written language anew”.
AS PROVIDED IN ICOMOS EVALUATION

Mtskheta is a multi-layered monument, its surviving architectural monuments and the excavated archaeological material testifying to the wide range of building activity and the high level of culture of the country from the 2nd millennium BC to the present era.

The architectural monuments are significant in the development of the architecture of Georgia and at the same time for the development of medieval architecture over the whole Christian area. They are also striking examples of the unity of architecture with its surrounding landscape.

Of special interest from an artistic and historical point of view are the early mosaics and metalwork discovered by excavation, along with the Armazi inscriptions, which provide a large database for the study of the origins of the Georgian language.

The archaeological remains and buildings in the ancient capital of Georgia are of high quality in terms of the light that they throw upon the social, political, and economic evolution of this mountain kingdom over more than four millennia. Whilst their individual value may not be high, their group value make this a site of outstanding value.

Recommendation

That this property be inscribed on the World Heritage List on the basis of criteria iii and iv:

- **Criterion iii** The group of churches at Mtskheta bear testimony to the high level and art and culture of the vanished Kingdom of Georgia, which played an outstanding role in the medieval history of its region.

- **Criterion iv** The historic churches of Mtskheta are outstanding examples of medieval ecclesiastical architecture in the Caucasus region.

4. STATEMENT OF AUTHENTICITY/INTEGRITY

EVALUATION OF THE AUTHENTICITY AT THE TIME OF INSCRIPTION

The archaeological sites are entirely authentic. So far as the architectural monuments are concerned, restoration and reconstruction work carried out in the 19th century was typical of its time, though it does not conform with modern conservation standards. In terms of materials and techniques, the ensemble retains a relatively high level of authenticity, whilst the authenticity of setting is total.

PRESENT EVALUATION OF THE AUTHENTICITY/INTEGRITY

There have not been significant changes in the authenticity of the site since inscription. The architectural and archeological monuments of Mtskheta can be considered entirely authentic.

The statement of outstanding universal value of the Historical Monuments of Mtskheta was prepared by the State Party in close collaboration with the international experts and submitted to the World Heritage Centre in 2012 SOC Report.
5. MANAGEMENT

LEGAL FRAMEWORK

a. The legal framework regulating the issues related to Mtskheta WHS (the laws, the Concordat, the protection zones) is described in details in the SoC reports of 2013, and is therefore omitted here.

b. In 2013, The National Agency for Cultural Heritage Preservation of Georgia became the project beneficiary of the EU funded TWINNING project “Support to the Institutional Development of the National Agency for Cultural Heritage Preservation of Georgia” with Ministry for Cultural Heritage and Activities of Italy and the Heritage Agency of Denmark as implementing partners. The key purpose of the Project is to improve governance in the field of cultural heritage protection through strengthening the capacities of the National Agency, enhancing the legal framework regulating the sector, *inter alia* regarding the World Heritage issues.

The National Agency’s 2014 program contains special allocation to engage the group of experts for elaborating the draft World Heritage law and related amendments. The draft documents are expected to be finalized by September 2014.

The TWINNING agenda has greatly facilitated the dialogues between the National Agency and the Patriarchate of Georgia over the issues related to the cultural heritage and among them World Heritage sites. The discussion is ongoing to adopt a Memorandum of Understanding that will focus particularly on the issues of joint site management, clarifying duties and responsibilities of each partner organization. These intentions were formally declared at the intermediate presentation of the project results to the project steering Committee on 19th December 2013, where the Mitropolitan Alaverdeli David represented the Patriarchate.

c. In 2013 in compliance with the decision 36 COM.7A.31 of the World Heritage Committee and based on the main principles of the 5C - World Heritage Strategic Objectives the National Agency has developed the Strategy for the State World Heritage Program with the purpose to improve coordination between national institutions in the framework of the World Heritage Convention (see annex 1). The framework is put forward to the Government of Georgia for approval. The National Agency and the Ministry of Culture and Monuments protection will continue working on the draft in 2014 and call the WHC and Advisory Bodies for assistance and guidance in the process.

d. In 2013 the National Agency launched the elaboration of the Urban Land-Use Master Plan for Mtskheta in response to the request by the World Heritage Committee (36 COM.7A.31). The World Heritage Centre and ICOMOS were consulted on the elaboration of the ToR. According to the recommendations, the tasks were split in two different projects with overall budget allocated by the state - 250,000 GEL. The public procurement tender was announced in August for two projects: (a) “Study of Mtskhe’t Cultural Landscape, impact assessment of the ongoing and planned developments and elaboration the value based guidelines for the sustainable management and development of this property” and (b) “Elaboration of the Mtskheta Historic area reference plan and regulatory documentation”. The winning company provided the multidisciplinary team of experts (urban planning, landscapes, art history, architecture, geography, ecology, law, etc.) as well as representatives of the Patriarchate.
included in the team. The regular co-ordination meetings with the Agency’s so called Inspection Team (the team of experts supervising implementation of the project) were held to ensure the achievement of successful results. Specially for this project the representative of ICOMOS Georgia was contracted to ensure methodological guidance for the project team. On 23 November, 2013 the extended co-ordination meeting was held at the Ministry of Culture with participation of Ms. Marine Mizandari, First Deputy Minister of Culture and Monuments Protection and Mr. Dimitri Khundadze, Mtskheta Majoritarian. The meeting aimed at discussing project progress. The further meetings and consultation with the Inspection Team are expected to be held this year in the course of the projects implementation. The documents are expected to be finalized by the end of 2014.

e. It is expected that the project will provide for final proposal for minor boundary modification of Mtskheta World Heritage site to allow the enhanced and unified buffer zone of the site as proposed by the draft Management Plan (submitted to the WHC in 2012) and, together with other factors described above, will make it possible to present the proposal for consideration to the World Heritage Centre in 2015.

**MANAGEMENT**

a. The stakeholders in management of the site and buffer zone are the local government of the Mtskheta municipality, the Patriarchate of Georgia, the Ministry of culture and Monuments Protection and the National Agency for cultural Heritage Preservation of Georgia and the Mtskheta Museum –Reserve.

b. The Ministry of Culture and Monuments Protection of Georgia is the main body to ensure the protection of the visual integrity of the site within the designated protection zones of the property. The Ministry provides mandatory advice to the local Municipality on all development projects and construction activities. The recommendation of the Minister is mandatory by law on Cultural Heritage and forms part of the process of issuing a building permit by the local municipal services.

c. The physical conservation of the property is undertaken by the National Agency for Cultural Heritage of Georgia. According to the Law, the Agency issues a permit for all types of conservation-restoration works on the listed buildings. The Agency is responsible for monitoring and maintaining a good state of conservation of the site, providing a proper methodology for interventions, and providing a general management framework as well as visitor facilities and information. At the local level the Museum-Reserve is responsible for monitoring of the state of conservation of the monument.

d. The Patriarchate of Georgia is involved in the management process as the owner of the property. The consent of an owner is formally required by law before the permit for restoration/conservation is issued by the National Agency. The Council for Ancient Georgian Art and Architecture, a body chaired by the Patriarch, co-operates, on behalf of the church, with the National Heritage Agency as well as the Ministry, and advises the church authorities at all levels on what interventions are appropriate.

e. In co-operation with the main stakeholders, the National Agency has elaborated the Management Plan for Mtskheta WHS in the framework of the project “Improving Management of the Historic Monuments of Mtskheta” implemented with the financial support of the World Heritage Fund.
f. In 2014 the National Agency is developing the necessary legal framework (the national law) to allow the legal status of the Management Plan and its further adoption and implementation. The national Law on World Heritage properties will serve as a basis for the official approval of the Management Plan and for its effective implementation with the involvement of all the stakeholders.

g. Mtskheta as a city with World Heritage monuments participates in the “War Free World Heritage cities” within the ENPI CIUDAD programme in cooperation with Byblos (Lebanon) and WATCH. Due to several factors the submission of the nomination for the Enhanced Protection for the Mtskheta WHS in compliance with the Second Protocol to the Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict was postponed to 2014. In 2013, a number of steps were taken towards the risk management. On the initiative of the Municipality of Mtskheta and with institutional support of the Ministry of Culture and Monuments Protection of Georgia the meeting was held with participation of the Ministry of Defence, Ministry of Internal Affairs Ministry of Justice, the NACHPG and the Patriarchate of Georgia, aimed at establishment of the Inter-agency Coordination Board for Risk Management of Mtskheta WHS. The main goals of the board are to ensure implementation of the 1999 Second Protocol of the Hague Convention, implement the preventive measures for safeguarding of Mtkshta WHS in time of peace and take relevant measures in the period of possible armed conflict. The Training focusing on developing of a model for civil-military cooperation for the protection of movable and immovable heritage in full respect of the international law was held in September, 2013 with the participation of wide range of stakeholders.

**NATIONAL INSTITUTION**

The management of the WH sites at the national level is entitled to the National Agency for Cultural Heritage Preservation – the legal entity under the of the Ministry of Culture and Monuments Protection.

The UNESCO and International Relations Unit of the Agency, facilitates co-ordination of the processes at the national level related to the WH sites, elaborates annual programs and overall strategy related to WH sites as well as the issues related to the national tentative list.

The National Agency is responsible for monitoring and maintaining good state of conservation of the site, providing proper methodology for interventions and issuing permits, providing a general management framework as well as visitor facilities and information.

**Address of the institution:**
National Agency for Cultural Heritage Preservation  
N27a Atoneli str, 0105, Tbilisi, Georgia  
Director General: Merab Bochoidze

**MANAGEMENT AGENCY**

The local management agency is the Great Mtskheta Archaeological Museum Reserve - a structural division of the National Agency for Cultural Heritage Preservation. The National Agency provides funding and supervision for the Mtskheta museum-reserve. For more information see the SoC reports of 2013, 2012, etc.
6. NATIONAL INVENTORY

The Historical Monuments of Mtskheta are registered as Listed Properties of national importance according to the Law on Cultural Heritage of Georgia. For more information see the SoC reports of 2013, 2012 etc.

7. RAISING PUBLIC AWARENESS

Educational program “Archaeology for kids” at Samtavro Valley has been carried out for recent four years, aiming at raising children's interest towards history, archaeology and cultural heritage, and developing skills of creative and analytical skills. In 2013 over 2000 children took part in the program and received special Certificates of achievement. The program is expected to continue in 2014. The Marketing Unit of the NACHPG held a number of presentations in Georgian schools throughout the country raising awareness in the field of cultural heritage and promoting the program “Archaeology for kids”.

In 2013 the framework of the project “War Free World Heritage Listed Cities” and in cooperation with the National Committee of ICOMOS, the second cycle of public awareness promotion (PAP) took place in Mtskheta addressing school children and covered issues of cultural heritage protection, needs of preservation and measures to be taken for safeguarding cultural heritage in times of armed conflicts.

Within the EU funded project “Regional Co-operation for Cultural Heritage Development” series of awareness raising seminars were held in Mtskheta on September 30th – October 4th. Seminars targeted several groups of the local community, such as the staff of municipality and local museum, owners of heritage sites, school teachers and school children. The seminars included presentations about the importance of heritage and its preservation, as well as heritage values of Mtskheta and its current challenges. Discussion of the presented topics and others of concern followed the presentations and engaged the whole audience. School seminars were interactive and included learning activities for children. More information can be accessed online: http://www.rcchd.icomos.org.ge/?l=E&m=3&id=95.

This activity of ICOMOS Georgia also envisages creation of a Teachers' Manual for a short heritage course for secondary schools in Georgia. The activity is managed by ICOMOS Georgia in close collaboration with Ministry of Education and Science of Georgia.

The teachers’ manual in Georgian language will be prepared to be distributed to the teachers participating in the seminars and made available for free download on the project site as well as distributed among secondary schools in print and CD-ROM versions throughout Georgia’s secondary schools via the Ministry of Education and Science of Georgia regional resource centres. The manual will include five lesson plans for a short heritage course that will be incorporated in social sciences' course. The manual will include course content and visual material accompanied with suggestions for group and individual work, ideas for homework and student project. The manual shall make reference to existing awareness raising training material developed by ICCROM and UNESCO, while focusing on country specific needs and background.
8. FACTORS AFFECTING THE PROPERTY

The main factor affecting the property still remains the lack of legal management instruments. The State Party makes every effort to improve the current situation. It is expected that the adoption of the law on World Heritage will be a significant turning moment in this process. The law will allow formal approval of the Management Plan at the government level and its effective implementation.

It is also expected that the elaboration of the Cultural Heritage Reference Plan and Urban regulations for Mtskheta by the National Agency will provide for further approval of the document by the local municipal council and thus will guarantee sustainable heritage oriented decision making at local as well as national levels.

9. MONITORING

The National Agency provides regular monitoring of all World Heritage properties in Georgia. The monitoring missions visit the properties annually and in case of emergency to evaluate the state of conservation of the sites. The regular reports on state of conservation of the property are submitted from the monitoring expert of the Great Mtskheta Archaeological Museum-Reserve. Based on the monitoring reports the necessary preventive, conservation or rehabilitation measures and respective budgets are estimated by the Agency staff and considered within the Action Plan of the National Agency.

10. PROTECTION AND CONSERVATION

10.1. Svetitskhoveli Cathedral

a. In 2012, with the purpose to prepare the comprehensive Conservation Plan for Svetitskhoveli Cathedral, the National Agency for Cultural Heritage Preservation of Georgia established cooperation with Eng. Prof. Giorgio Crocci for the assessment of the current condition of the Site and elaboration of short and long-term action plans for different conservation issues of the Cathedral. The two-phase project ended in 2013.

b. The project implied the implementation of the structural investigations: a) video endoscopic investigations, b) sonic tests c) mineralogical analysis of the mortar d) mechanical laboratory tests e) set up of the monitoring system for the control of cracks. Besides, the structural analysis implementing a Finite Elements Model was performed to evaluate the vulnerability assessment and risks. The project team elaborated recommendations and action plan for possible consolidation-conservation works for the Cathedral (see annex 2).

c. In the framework of the project, the working group implemented two missions on 16-21 September, 2013 and 16-18 December, 2013. During the 2nd mission, prof. Giorgio Crocci together with eng. Cristiano Russo delivered the public presentation on the implemented works and held discussions with Georgian experts on the relevant issues.

d. The investigation results provide an essential database for the further planning and implementation of an integrated consolidation-conservation project of Svetitskhoveli Cathedral.

e. In 2013 the National agency allocated budget for research and conservation of stone reliefs of West Façade of the Cathedral. Mr. Simon Warrak was to undertake this very
important task. However due to several objective reasons related to timing of works and availability of the experts, the implementation of the project was not possible in 2013. The perspectives are discussed with the Ministry of Culture to continue working into this direction as well as to develop larger scale conservation works on the Cathedral in the forthcoming years on sustainable basis.

f. The allocation for further enhancement of the Svetitskhoveli conservation program is provided in 2014 budget of the National Agency.

10.2 Jvari Monastery

There has been no major intervention and projects related to Jvari Monastery in 2013. The conservation state of the Monuments remains satisfactory.

10.3 Samtavro Monastery

The implementation of the project of the candle shop was launched by the Monastery in 2014 in accordance with the design presented and agreed with the World Heritage Centre and ICOMOS. The archaeological supervision of the process revealed two burial sites and thus the works were suspended by the National Agency to allow detailed archaeological survey.

In 2014 the National Agency has also intervened in the process of illegal construction of the garage within the walls of the Monastery in the buffer zone. Currently the projects designs are being developed by the Monastery to discuss the possibility of construction of the proposed garage by the National Agency.

The proposal for restoration of the belfry was prepared by the National agency and submitted to the World Heritage Centre in Autumn 2013.

10.4 Armaztsikhe-Bagineti archaeological site

a. In 2013 the 4th phase of archaeological excavations were implemented in Armaztsikhe Bagineti by the National Museum of Georgia. The excavations revealed several dwellings and other archaeological remains that are subject to research and further analysis. The excavations are expected to continue in 2014.

b. As the investigations continue at the site, the NACHPG arranged the temporary roofing to protect the archaeological finds from natural hazards (see annex 3).

11. PREVIOUS WORLD HERITAGE COMMITTEE

Decision 37 COM 7A.33

The World Heritage Committee,
1. Having examined Document WHC-13/37.COM/7A,
2. Recalling Decisions 34 COM 7A.27, 35 COM 7A.30 and 36 COM 7A.31, adopted at its 34th (Brasilia, 2010), 35th (UNESCO, 2011) and 36th (Saint-Petersburg, 2012) sessions respectively,
3. Acknowledges the detailed information provided by the State Party on the progress made to implement the corrective measures and urges the State Party to continue its work on all the corrective measures adopted at its 34th session (Brasilia, 2010);
4. Reiterates its request to the State Party to submit a minor boundary modification proposal for a unified buffer zone of the property to enhance the protection of the property and to allow a clear understanding of the archaeological and visually sensitive areas around the property;
5. Notes that a draft Management Plan was submitted by the State Party and encourages the State Party to strengthen the Plan by clearly identifying the attributes of the Outstanding Universal Value as the basis for legal protection, planning processes and management;

6. Also notes that the State Party has halted inappropriate developments within the property and its setting and also urges the State Party to finalize the Urban Land-Use Master Plan, including zoning regulations with particular emphasis on the establishment of no-construction zones, strict limits to development rights and a conservation master plan and which should take into consideration the Outstanding Universal Value of the property, its specific landscape setting, as well as important views and connection lines;

7. Encourages the State Party to adopt as a matter of urgency the Urban Land-Use Master Plan as a major step towards the removal of the property from the List of World Heritage in Danger;

8. Notes with concern that the proposed location of the waste water treatment plant would have a highly negative impact on the sensitive river landscape that forms the setting for the monuments, and requests the State Party as a matter of urgency to re-locate the plant to a position that does not impact adversely on the Outstanding Universal Value of the property;

9. Takes note that the State Party plans to develop a national law for World Heritage properties in Georgia, as well as a “5C World Heritage Programming Approach”;

10. Also requests the State Party to submit to the World Heritage Centre, by 1 February 2014, an updated report on the state of conservation of the property and the implementation of the above, for examination by the World Heritage Committee at its 38th session in 2014;

11. Decides to retain the Historical Monuments of Mtskheta (Georgia) on the List of World Heritage in Danger.

12. IMPLEMENTATION BY STATE PARTY

The major steps undertaken by the state party to implement the decision of the Committee are stipulated in the chapter 5.

As regards to the project for the Waste Water Treatment Plan – the project was cancelled by the local municipality, in accordance with the recommendations of the World Heritage Centre and the Committee decision. The alternative solutions for improving and arranging the sewerage infrastructure of the town are being sought.

13. CONCLUSIONS

The conclusions presented below are aimed at contributing to the analysis which will facilitate to the Advisory Body and the Secretariat the preparation of the Committee draft decision.

Strengths

- Preparation of the Urban Land-Use Master Plan is underway and will be completed and adopted by the end of 2014
- Elaborated draft strategy for the State Program on the World Heritage will be finalized in consultation with the World Heritage Centre and adopted by the Government of Georgia by the end of 2014
- State Party took into consideration the ICOMOS comments on the inappropriate location of the waste treatment plant and is discussing other appropriate options that will be agreed with the World Heritage Centre and its Advisory Bodies.
- The State Party halted the inappropriate developments within the property and its setting.
– Involvement of the best international experts ensured in survey and preparation of the conceptual framework for Svetiskhoveli Cathedral
– Raised public awareness and attention to Mtskheta WHS
– The cooperation between the stakeholders is developing on increasingly sustainable basis

**Weaknesses**

The State Party makes its every effort towards removal of all the current weaknesses regarding Mtskheta WHS, in particular:

- Elaboration of the urban regulatory documents is in progress
- Improvement of the legal framework is in progress
- Improvement of the Management Plan for Mtskheta WHS according to the recommendations received from World Heritage Centre Advisory Body is in progress.
Report on the State of Conservation

1. Response from the State Party to the World Heritage Committee’s Decision(s)

a. Corrective measures taken by the State Party in reply to the World Heritage Committee’s Decision(s):

<table>
<thead>
<tr>
<th>Decision: 37 COM 7A.33</th>
<th>State Party response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reiterates its request to the State Party to submit a minor boundary modification proposal for a unified buffer zone of the property to enhance the protection of the property and to allow a clear understanding of the archaeological and visually sensitive areas around the property;</td>
<td>According to the Terms of Reference, the Urban Land-Use Master Plan of the city of Mtskheta will define the buffer zone of the property</td>
</tr>
<tr>
<td>Urges the State Party to finalize the Urban Land-Use Master Plan, including zoning regulations with particular emphasis on the establishment of no-construction zones, strict limits to development rights and a conservation master plan and which should take into consideration the Outstanding Universal Value of the property, its specific landscape setting, as well as important views and connection lines;</td>
<td>The State Party started elaboration of the Urban Land-Use Master Plan in 2013 and will finalize the document by the end of 2014.</td>
</tr>
<tr>
<td>Notes with concern that the proposed location of the waste water treatment plant would have a highly negative impact on the sensitive river landscape that forms the setting for the monuments, and requests the State Party as a matter of urgency to re-locate the plant to a position that does not impact adversely on the Outstanding Universal Value of the property;</td>
<td>On the basis of the ICOMOS comments regarding the inappropriate location of the waste water treatment plant, the State Party withdrew its proposal and is discussing new positions that will not have the negative impact on Mtskheta WHS setting and affect the Outstanding Universal Value of the property.</td>
</tr>
</tbody>
</table>
b. Progress towards the removal of the property from the list of the World Heritage in Danger

a. The 2013 was marked with the intensive progress in the implementation of the corrective measures defined by the WHC. The State Party started work on the elaboration of the national law on World Heritage properties in the scope of the EU funded project TWINNING Support to the institutional development of the National Agency for Cultural Heritage Preservation of Georgia”.

b. The draft State World Heritage Program was elaborated and submitted to the Government. The Finalization of the Program will take place in 2014 with close co-operation with the WHC.

c. The elaboration of the Urban Land-Use Master Plan for the city of Mtskheta started by the initiative of the National Agency for Cultural Heritage Preservation and in cooperation with the Ministry of Culture and Monuments Protection and Mtskheta local government.

d. The preliminary survey for further preparation of the comprehensive conservation plan for Svetitskhoveli Cathedral was concluded.

c. The success factors and difficulties in implementing the corrective measures

The close co-operation established with the internationally recognized conservation experts mark successful efforts of the State Party towards improving the conditions of the site.

The elaboration of the Urban Land-Use Master Plan for the city of Mtskheta and its approval by the local government together with the Management Plan for Mtskheta WHS will be the most important factors in 2014 to facilitate the removal of the property from the list of the World Heritage in Danger.

The communication and dialogue between different stakeholders of the property is notably improved and will be further strengthened in the process of management of the Mtskheta WHS, based on the Management Plan and the Land-Use Master Plan.

d. The timeframe for corrective measures

The corrective measures indicated in this report were implemented in 2013 and/or are planned for 2014 as confirmed by the annual budget of the National Agency for Cultural Heritage Preservation of Georgia.

2. Other current conservation issues

See the SoC report 2014.

3. Potential interventions

- Preparation of the conservation project documentation for Svetitskhoveli Cathedral
- Preparation of the Mtksheta Archaeological Museum building adaptation-development project
- Further conservation of the archaeological ruins of Armaztsikhe-Bagineti archaeological site
- Preparation of Pitiaksh Royal bath conservation project and implementation, Armaziskhevi

Signature on behalf of the State Party:

Marine Mizandari
First Deputy Minister of Culture and Monuments Protection of Georgia
1. Introduction

Georgia acceded the Convention concerning the Protection of the World Cultural and Natural Heritage in 1992 by which the State recognized the regulations of the Convention and took the responsibility of its implementation at national level.

Over the last 20 years due to inadequate implementation of the Convention the situation created around the World Heritage properties of Georgia is alarming – for reasons of inappropriate management and legal mechanisms the Committee deferred two submitted nominations in 1999. From three Georgian sites inscribed in early 90s in the World Heritage List two of them in recent 5 years were inscribed in the World Heritage List in Danger by the decision of the World Heritage Committee.

The analysis of the current situation as well as the recommendations of the World Heritage Committee prove that the problems solution goes beyond the competence and authority of a singly institution, including the Ministry of Culture and Monuments Protection of Georgia.

The World Heritage Committee made repeated requests to the State Party to elaborate the State Program on World Heritage and relevant legislative and intergovernmental management mechanisms.

In view of the above said the present document is a Strategy that will serve as a basis for the elaboration, approval and implementation of the State Program on World Heritage and its relative management mechanisms in close cooperation with the World Heritage Centre and different national institutions.

2. State Budget Priorities

Culture, Religion, sport, youth
3. Estimated period of implementation and reporting

The reports on the implementation process will be provided annually at the end of each calendar year.

4. Strategy Aim

Taking into consideration the principles of the Global Strategy for representative, balanced and credible World Heritage List, in accordance to the Operational Guidelines and the recommendations of the World Heritage Committee, the aim of the National State Program for World Heritage is to facilitate the improvement of the implementation of the World Heritage Convention at the national level in Georgia, implementing the State obligations as provided by the Convention and establishment of the effective state mechanism for the World Heritage protection and management.

5. Strategy Content

The National State Strategy for World Heritage is based on the recommendation of the World Heritage Committee (36th session, 36 COM.7A.31, St Petersburg, 2012) on the elaboration of the World Heritage State Program according to the strategic objectives specified as 5Cs adopted and further enhanced by the World Heritage Committee in 2002-2007.

In accordance to the strategic objectives of the World Heritage Convention the State Program for World Heritage of Georgia is based on the following main components:

a) Ensuring the **Credibility** of the world heritage list
b) **Conservation** of the World Heritage Sites
c) **Capacity building** in world heritage management
d) **Communication** for public awareness and participation in world heritage issues
e) Raising the role of local **Communities** in the implementation of the World Heritage Convention

5.1 Ensuring the credibility of the world heritage list

**Aim:** To support the credibility of the world heritage list through the credible nominations from Georgia in accordance with the priorities of the Global Strategy.

In order to achieve the abovementioned the State ensures the implementation of the following activities:
- Conducting and facilitating scientific studies and inventories across the country taking into consideration the WH Global Strategy priorities to identify and valorize the cultural and natural heritage, *inter alia*, intangible heritage resources of the country;
- Updating the national Tentative List of the World Heritage Convention in accordance with the Global Strategy and the priorities of the World Heritage;
- Analysis of the Georgian World Heritage sites and the nominations submitted with a view to preparation of future successful nominations;
- Preparing and presenting the nominations to the World Heritage list in consultation of the wider pool of stakeholders and general public, with the scientific justification of the OUV.

5.2 Conservation of the World Heritage Sites

*Aim:* To ensure the adequate state of conservation of the Georgian World Heritage sites and the sites inscribed in the National Tentative list in accordance with the international conservation and rehabilitation standards.

To achieve the abovementioned the State implements the following activities:

- Improvement of the state of conservation of the World Heritage sites and the sites of the national Tentative List in accordance with the international standards;
- Updating the information on the World Heritage and the national Tentative List sites, including graphical and cartographic documentation and detailed description, in accordance with the provisions of the respective Georgian legislation;
- Definition and adoption of the boundaries of the World Heritage and the national Tentative List sites and their buffer zones;
- Multidisciplinary survey and evaluation of the state of conservation of the World Heritage and the national Tentative List sites;
- Systematization, saving and sharing of the information on sites through the national database;
- Elaboration and implementation of the preventive conservation programmes for the sites;
- Elaboration and adoption of the Conservation Plans for the World Heritage and the Tentative List sites
- Implementation of regular monitoring of the sites.
5.3 Improving the Capacity for World Heritage Management

**Aim:** To establish the national system for World Heritage management in accordance with the state priorities for democratic and decentralized management.

To achieve the abovementioned the State ensures the following activities:

- To establish the programs for vocational training in world heritage management for the stuff and young generations;
- Implementing the interdisciplinary training courses and with these aims ensuring a) integration in the international learning infrastructure and b) creating of the national learning infrastructure;
- Methodological interpretation and legal definition of the Management Plan and its content;
- Elaboration and adoption of the Management Plans for the World Heritage and national Tentative List sites;
- Establishment of the working groups at the government and interdepartmental level for the adequate distribution of the duties and tasks related to the effective administration of the World Heritage and national Tentative List sites in Georgia;
- Upgrade of the national legislation with an aim to improvement of protection of the World Heritage and national Tentative List sites and harmonizing with the Convention, its Operational Guidelines as well as relevant international charters ratified by Georgia;
- Providing adequate financial-technical equipment for the implementation of the above activities.

5.4 Communication with wider public and ensuring participation in implementation of the WH convention

**Aim:** To establish the transparent, participatory and inclusive national system for implementation of the World Heritage Convention.
To ensure the above-mentioned the State undertakes the following activities:

- Supporting the dissemination of the information on the World Heritage Convention, encouraging media to provide regular and competent information on world heritage issues;
- Providing adequate signage for the World Heritage sites in Georgia;
- Ensuring the accessibility of information through the national database, web portal and other Internet resources on cultural heritage;
- Hold regular public meeting and discussions regarding the issues of world heritage;
- Support and encourage the NGOs and trade unions to work in the World Heritage field;
- Create and implement the mechanism for involving civil society in the decision making on WH sites;
- Establishment of different educational and awareness raising youth programmes.

5.5 Increasing the role of local communities in the implementation of the World Heritage convention

**Aim:** To increase the role of the local communities in World Heritage Convention implementation in accordance with the State Priorities for democratic and decentralized State priorities.

To achieve the above-mentioned the State undertakes the following activities:

- Creating and implementing the mechanism for informing and involving the local population in consultations and decision making process;
- Supporting creation of the local community organizations in order to ensure the representation of local communities living in the World Heritage properties or in their buffer zones;
- Involving local communities in awareness raising and educational programmes including the sustainable utilization of cultural and natural heritage resources;
- Establishing the educational courses and training programs with the aim of the involving local communities in preventive conservation monitoring and other relevant activities;
- Encouraging local population for sustainable utilization of cultural and natural resources, inter alia, adopting and implementing the financial incentives and small grants program;
- Identification of the intangible cultural heritage resources practiced by the local population and establishing programmes for their safeguarding and enhancement.

6. Expected Outcomes

As a result of the Strategy realization implementation of the World Heritage Convention will be improved and the following goals will be achieved:

- Harmonized national Tentative List in accordance with the World Heritage priorities;
- Improved state of conservation of Georgian World Heritage sites in compliance with international standards;
- Improved management of World Heritage sites in accordance with international norms;
- Professional resources are developed in the management and conservation of World Heritage sites as well as in the related fields;
- Increased involvement of local communities in the world heritage related issues;
- Increased involvement and participation of the civil society in world heritage activities;
- The Georgian World Heritage sites are removed from the World Heritage List in Danger;
- New successful nominations are submitted to the World Heritage List;
- Georgia successfully participates in the activities of UNESCO and World Heritage Committee.
7. Evaluation Indicators

<table>
<thead>
<tr>
<th>#</th>
<th>Result</th>
<th>Evaluation Indicator</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The national Tentative List is updated in compliance with the World Heritage priorities</td>
<td>Not less than 50% top-priority types of world heritage are presented in the Tentative List</td>
<td>The TL became more representative and diverse</td>
</tr>
<tr>
<td>2</td>
<td>Improved state of conservation of Georgian World Heritage sites in compliance with international standards;</td>
<td>Two of the World Heritage Sites of Georgia are removed from the World Heritage List in Danger and listed back in the World Heritage List</td>
<td>The State Party got the positive assessment from the ICOMOS monitoring missions and World Heritage Committee</td>
</tr>
<tr>
<td></td>
<td>All the World Heritage and national Tentative List sites have adopted conservation plans, updated documentation, including graphical materials</td>
<td></td>
<td>The physical condition of sites do not need significant unforeseen expanses for the restoration-rehabilitation works</td>
</tr>
<tr>
<td>3</td>
<td>Improved management of World Heritage sites in accordance with international norms</td>
<td>Two of the World Heritage Sites of Georgia are removed from the World Heritage List in Danger and listed back in the World Heritage List</td>
<td>The State Party got the positive assessment from the ICOMOS monitoring missions and World Heritage Committee</td>
</tr>
<tr>
<td></td>
<td>Sites have approved management plans and management structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>the management plan status is defined in the national legislation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Georgian parliament adopted the Law on World Heritage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The State Committee of intergovernmental management on world heritage issues is created and operates successfully</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local communities participate in the management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Professional resources are developed in the management and conservation of World Heritage sites as well as in the related fields</td>
<td>Trained not less than 50 professionals according to different directions of world heritage management and conservation</td>
<td>Georgian students and professionals are trained in leading universities worldwide</td>
</tr>
<tr>
<td></td>
<td>Not less than 20 young experts have BA / Masters in world heritage management</td>
<td>the international network in the fields of experience sharing, education and professional development is established</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>The interdisciplinary trainings system on world heritage issues is elaborated and operates successfully</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><strong>Increased involvement of local communities in the world heritage related issues</strong></td>
<td>Not less than three community organizations are created</td>
<td>Legislative mechanisms ensuring involvement of communities are elaborated, adopted and successfully operate</td>
</tr>
<tr>
<td>6</td>
<td><strong>Increased involvement and participation of the civil society in world heritage activities</strong></td>
<td>World Heritage sites are provided by adequate signage and other relevant information instruments</td>
<td>World heritage topics is successfully used for marketing and promotion of national and local products</td>
</tr>
<tr>
<td></td>
<td>TV and radio broadcasts, newspaper columns dedicated to world heritage topics</td>
<td></td>
<td>World heritage topics are used in tourism programs and touristic routes</td>
</tr>
<tr>
<td></td>
<td>World heritage topics are included in school and university educational programs</td>
<td></td>
<td>Educational programs are based on international experience and on the methodology of UNESCO educational program &quot;WORLD HERITAGE IN YOUNG HANDS&quot;</td>
</tr>
<tr>
<td></td>
<td>The educational program for school children and youth is created and implemented</td>
<td></td>
<td>Georgian youth participates in world heritage youth forums</td>
</tr>
<tr>
<td>7</td>
<td><strong>The Georgian World Heritage sites are removed from the World Heritage List in Danger</strong></td>
<td>Two of the World Heritage Sites of Georgia are removed from the World Heritage List in Danger and listed back in the World Heritage List</td>
<td>The State Party receives positive comments from ICOMOS monitoring missions and World Heritage Committee</td>
</tr>
<tr>
<td>8</td>
<td><strong>New successful nominations are submitted to the World Heritage List</strong></td>
<td>At least one nomination is prepared and submitted to the WHC</td>
<td>New nomination is approved by the World Heritage Committee</td>
</tr>
<tr>
<td>9</td>
<td><strong>Georgia successfully participates in the activities of UNESCO and World Heritage Committee</strong></td>
<td>At least 1 international event on world heritage topics is held in Georgia on an annual basis</td>
<td>The State Party receives positive assessments from ICOMOS and World Heritage Committee</td>
</tr>
<tr>
<td>Representatives from Georgia participate in thematic working groups of the World Heritage Convention</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In consultations with regional states Georgia nominates its candidate to the World Heritage Committee</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
NATIONAL AGENCY FOR CULTURAL HERITAGE PRESERVATION

SVETITSKHOVELI CATHEDRAL
MTSKHETA (GEORGIA)

SPC STUDIO PROGETTAZIONE E CONTROLLI
Roma - via della Fonte di Fauno, n° 2a
tel. 06.5746335-06.5747860; fax 06.5781268
mail@spc-engineering.it
www.spc-engineering.it

Project Engineers:
Prof. Eng. Giorgio Croci
Dott. Eng. Cristiano Russo

Collaborators:
Dott. Eng. Giulio Rossi
Geom. Tiziano Stella

STRUCTURAL INVESTIGATIONS

FINAL REPORT

<table>
<thead>
<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
<th>Written</th>
<th>Verified</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11/12/2012</td>
<td>1*ISSUE</td>
<td>Stella/Rossi</td>
<td>C. Russo</td>
<td>G. Croci</td>
</tr>
</tbody>
</table>
INDEX

1. INTRODUCTION .................................................................................................................. 4

2. VIDEOENDOSCOPIC INVESTIGATION ............................................................................. 6
   2.1. INVESTIGATIONS LOCATION .................................................................................... 7
   2.2. VIDEOENDOSCOPY V-1 ............................................................................................ 8
   2.3. VIDEOENDOSCOPY V-2 ........................................................................................... 11
   2.4. VIDEOENDOSCOPY V-3 ............................................................................................ 14
   2.5. VIDEOENDOSCOPY V-4 ............................................................................................ 17
   2.6. VIDEOENDOSCOPY V-5 ............................................................................................ 20
   2.7. VIDEOENDOSCOPY V-6 ............................................................................................ 23
   2.8. VIDEOENDOSCOPY V-7 ............................................................................................ 26
   2.9. VIDEOENDOSCOPY V-8 ............................................................................................ 29
   2.10. VIDEOENDOSCOPY V-9 ......................................................................................... 32
   2.11. VIDEOENDOSCOPY V-10 ...................................................................................... 35
   2.12. VIDEOENDOSCOPY V-11 ...................................................................................... 38
   2.13. VIDEOENDOSCOPY V-12 ...................................................................................... 41
   2.14. VIDEOENDOSCOPY V-13 ...................................................................................... 44
   2.15. VIDEOENDOSCOPY V-14 ...................................................................................... 47
   2.16. VIDEOENDOSCOPY V-15 ...................................................................................... 50
   2.17. VIDEOENDOSCOPY V-16 ...................................................................................... 53
   2.18. VIDEOENDOSCOPY V-17 ...................................................................................... 56
   2.19. VIDEOENDOSCOPY V-18 ...................................................................................... 59
   2.20. VIDEOENDOSCOPY V-19 ...................................................................................... 62
   2.21. VIDEOENDOSCOPY V-20 ...................................................................................... 65
   2.22. VIDEOENDOSCOPY V-21 ...................................................................................... 68
   2.23. VIDEOENDOSCOPY V-22 ...................................................................................... 71
   2.24. VIDEOENDOSCOPY V-23 ...................................................................................... 74
   2.25. VIDEOENDOSCOPY V-24 ...................................................................................... 77
   2.26. VIDEOENDOSCOPY V-25 ...................................................................................... 80
   2.27. VIDEOENDOSCOPY V-26 ...................................................................................... 83
   2.28. VIDEOENDOSCOPY V-27 ...................................................................................... 86
   2.29. VIDEOENDOSCOPY V-28 ...................................................................................... 89
   2.30. VIDEOENDOSCOPY V-29 ...................................................................................... 92
   2.31. VIDEOENDOSCOPY V-30 ...................................................................................... 95
   2.32. VIDEOENDOSCOPY V-31 ...................................................................................... 98
2.33. VIDEOENDOSCOPY V-32 .......................................................... 101
2.34. VIDEOENDOSCOPY V-33 .......................................................... 103
2.35. VIDEOENDOSCOPY V-34 .......................................................... 106
2.36. VIDEOENDOSCOPY V-35 .......................................................... 108
2.37. VIDEOENDOSCOPY V-36 .......................................................... 111
2.38. VIDEOENDOSCOPY V-37 .......................................................... 114
2.39. VIDEOENDOSCOPY V-38 .......................................................... 117
2.40. VIDEOENDOSCOPY V-39 .......................................................... 119
2.41. VIDEOENDOSCOPY V-40 .......................................................... 121
2.42. VIDEOENDOSCOPY V-41 .......................................................... 124
2.43. VIDEOENDOSCOPY V-42 .......................................................... 127
2.44. VIDEOENDOSCOPY V-43 .......................................................... 130
2.45. VIDEOENDOSCOPY V-44 .......................................................... 133
2.46. VIDEOENDOSCOPY V-45 .......................................................... 135
2.47. VIDEOENDOSCOPY V-46 .......................................................... 138

3. SONIC TESTS .................................................................................. 141

3.1. LOCATION OF THE SONIC TESTS .................................................. 143
3.2. SONIC TEST S-1 .......................................................................... 144
3.3. SONIC TEST S-2 .......................................................................... 146
3.4. SONIC TEST S-3 .......................................................................... 148
3.5. SONIC TEST S-4 .......................................................................... 150
3.6. SONIC TEST S-5 .......................................................................... 152
3.7. SONIC TEST S-6 .......................................................................... 154
3.8. SONIC TEST S-7 .......................................................................... 156

4. MINERALOGICAL ANALYSIS OF THE MORTAR .................................. 158

4.1. SAMPLE 1 .................................................................................. 159

5. MECHANICAL LABORATORY TESTS ................................................... 163

5.1. RESULTS .................................................................................... 164
5.2. TEST CERTIFICATE .................................................................... 170

6. MONITORING SYSTEM .................................................................... 172

6.1. TECHNICAL CHARACTERISTICS ................................................... 172
6.1.1. Data Acquisition System .......................................................... 172
6.1.2. Displacement Transducer .......................................................... 174
6.1.3. Thermal Sensor ........................................................................ 175
6.1.4. Multipolar Shielded Cables ........................................................ 176
6.2. LOCATION OF THE INSTRUMENTATION ................................................................. 177
6.3. PHOTOGRAPHIC DOCUMENTATION .................................................................. 180
6.4. PLOT OF SAMPLED VALUES ............................................................................. 184
   6.4.1. Displacement transducers ........................................................................ 185
   6.4.2. Thermal sensors .......................................................................................... 191

7. ANALYSIS OF THE RESULTS .................................................................................. 193

    7.1. VERTICAL STRUCTURES .............................................................................. 194
    7.2. VAULT ........................................................................................................... 203
    7.3. MECHANICAL LABORATORY TESTS ............................................................. 205
    7.4. MINERALOGICAL ANALYSIS OF THE MORTAR ........................................ 206
    7.5. MONITORING SYSTEM .................................................................................. 207
1. INTRODUCTION

This technical report concerns non-destructive investigation executed on the structure of Svetitskhoveli Cathedral in Mtskheta, Georgia, performed during November and December 2012.

In order to model the structural behaviour, especially in respect of the seismic action, it requires knowledge of the mechanical parameters of deformability and strength of materials, and in particular of the masonry. The characterization of the elements of the masonry (mortar, brick, sandstone, limestone and ophicalcite) was performed with the execution of mechanical laboratory tests into specimens taken in situ and mineralogical- petrographic analysis on a sample of mortar. In addition, in order to reduce the invasiveness of the qualification's investigation, sonic tests were conducted which allow to evaluate the homogeneity of the mechanical parameters in the different parts of the building, and videoendoscopic investigations in order to obtain information about the internal structure of masonry, possible presence of cavities or internal discontinuities, and the materials state of preservation.

The following table shows a summary table of all the non-destructive investigation carried out on the structures and testing of materials taken in situ.

<table>
<thead>
<tr>
<th>INVESTIGATION ON THE STRUCTURE AND MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>n. 46 VIDEOENDOSCOPIC INVESTIGATIONS</td>
</tr>
<tr>
<td>• n. 36 in the horizontal direction on the pillars and masonry approximatively 1 m from pavement level;</td>
</tr>
<tr>
<td>• n. 6 in the horizontal direction on the pillar approximately 6.5 m from pavement level;</td>
</tr>
<tr>
<td>• n. 3 in the horizontal direction on the pillar and masonry approximatively 10.75 m from pavement level;</td>
</tr>
<tr>
<td>• n. 2 on the vault, approximatively 7.5 m from pavement level.</td>
</tr>
<tr>
<td>n. 7 SONIC TESTS on the pillars and masonry</td>
</tr>
<tr>
<td>n. 1 MINERALOGICAL ANALYSIS OF THE MORTAR</td>
</tr>
<tr>
<td>n. 28 MECHANICAL LABORATORY TESTS</td>
</tr>
</tbody>
</table>
In addition, during the first mission in November 2012, was installed a monitoring system of the main lesions was found inside the Cathedral, consisting of the following instrumentation:

- n. 1 data acquisition system
- n. 6 displacement transducers
- n. 2 thermal sensors.

In chapter 6 lists technical characteristics of instrumentation, location and diagrams of acquisitions during the period November 2012 ÷ December 2013.
2. VIDEOENDOSCOPIC INVESTIGATION

Videoendoscopic investigation technique is lightly invasive mainly applied for knowing the state and typology of the building structures. The inspections have been executed inside perforations with diameters of 25 mm made by drill with rotation-percussion system. The videoendoscopies have been performed through videoendoscopy machine brand Olympus model IV 765 having probe diameter of 6 mm and total length of 500 cm. The system is constituted by a cable in steel cover net, to the extremity of which are present a microcamera with an optic fibre system complete of illumination by cold light. The camera’s head can turn up to 150° for inspection of the side on the cavities. The videoendoscope is connected to a recording system on magnetic-digital support for archive purpose.

For every inspected hole a schematic graphic representation of the stratigraphy is furnished. We give some photo-frames for any hole, extrapolated by the recording enclosing a digital format copy of the whole recording.
2.1. Investigations Location

SVETITSKHOVELI CATHEDRAL

VIDEOENDOSCOPIC INVESTIGATIONS

KEY OF SYMBOLS

- V = 0: approximately 1 m from pavement level
- V = 1: approximately 0.5 m from pavement level
- V = 2: approximately 0.25 m from floor pavement level
- V = 3: on the vault, approximately 2.2 m from pavement level

Diagram of the Cathedral with various labeled points indicating different levels and locations.
2.2. VIDEOENDOSCOPY V-1

**Structural element:** masonry

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 118 cm
- **Height from pavement level:** 100 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 118 cm (inspection end)
2.3. VIDEOENDOSCOPY V-2

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 117 cm
- **Height from pavement level:** 90 cm

**Videoendoscopic execution**

**Key plan**

<table>
<thead>
<tr>
<th>117</th>
<th>110</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
<th>0</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>117</th>
</tr>
</thead>
</table>

**Metrical Scale**

**Depth Scale**

**HOLE START**

**INSPECTION END**

**KEY OF SYMBOLS**

- **Sandstone**
- **Mortar**
- **Limestone**
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations via della Fonte di Fauno 2a - Tel +39-06-5746335 +39-06-5747860 Fax +39-06-5781268

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 117 cm (inspection end)
2.4. VIDEOENDOSCOPY V-3

**Structural element:** masonry

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 118 cm
- Height from pavement level: 67 cm

![Videoendoscopic execution](image)

**Key plan**

**Hole direction**

<table>
<thead>
<tr>
<th>118</th>
<th>110</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Metrical Scale**

**Depth Scale**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Ophicalcite
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 118 cm (inspection end)
2.5. **VIDEOENDOSCOPY V-4**

*Structural element:* pillar

*Hole:* horizontal direction

*Diameter:* 25 mm

*Length:* 119 cm

*Height from pavement level:* 90 cm

---

**Videoendoscopic execution**

---

**Key plan**

---

**Hole direction**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Cavity
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Object:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 119 cm (inspection end)
2.6. VIDEOENDOSCOPY V-5

Structural element: pillar

Hole: horizontal direction

Diameter: 25 mm
Length: 118 cm
Height from pavement level: 84 cm

Videoendoscopic execution

Key plan

Hole direction

Metrical Scale

Depth Scale

KEY OF SYMBOLS

- Sandstone
- Mortar
- Limestone
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
Object:
CATHEDRAL OF SVETITSKOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 118 cm (inspection end)
2.7. VIDEOENDOSCOPY V-6

**Structural element:** masonry  
**Hole:** horizontal direction  
  *Diameter:* 25 mm  
  *Length:* 115 cm  
  *Height from pavement level:* 83 cm

![Videoendoscopic execution](image)

**Key plan**  
**Hole direction**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
- Limestone
**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

---

**Photo frames extracted from video**

Depth 0 cm (hole start)  
Depth 10 cm  
Depth 20 cm  
Depth 30 cm  
Depth 40 cm  
Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 115 cm (inspection end)
2.8. VIDEOENDOSCOPY V-7

**Structural element:** masonry

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 115 cm
- **Height from pavement level:** 91 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Cavity
**Photo frames extracted from video**

Depth 0 cm (hole start)  
Depth 10 cm  
Depth 20 cm  
Depth 30 cm  
Depth 40 cm  
Depth 55 cm (cavity)
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHEITA

STRUCTURAL INVESTIGATIONS

Depth 60 cm
Depth 70 cm

Depth 80 cm
Depth 90 cm

Depth 100 cm
Depth 115 cm (inspection end)
2.9. VIDEOENDOSCOPY V-8

**Structural element:** pillar

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 116 cm
- Height from ground level: 84 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

---

KEY OF SYMBOLS

- Sandstone
- Mortar
- Limestone

---
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Structural Investigations

Depth 60
Depth 70

Depth 80
Depth 90

Depth 100 cm
Depth 116 cm (inspection end)
2.10. VIDEOENDOSCOPY V-9

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 118 cm
- **Height from ground level:** 96 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 118 cm (inspection end)
2.11. VIDEOENDOSCOPY V-10

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 119 cm
- **Height from ground level:** 95 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Cavity
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 119 cm (inspection end)
2.12. VIDEOENDOSCOPY V-11

**Structural element:** pillar

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 115 cm
- Height from ground level: 85 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Cavity
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

**Depth 60**

**Depth 70**

**Depth 80**

**Depth 90**

**Depth 100 cm**

**Depth 115 cm (inspection end)**
2.13. **VIDEOENDOSCOPY V-12**

**Structural element:** pillar  
**Hole:** horizontal direction  
  - Diameter: 25 mm  
  - Length: 118 cm  
  - Height from ground level: 80 cm
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 118 cm (inspection end)
2.14. VIDEOENDOSCOPY V-13

**Structural element:** masonry  
**Hole:** horizontal direction  
  *Diameter:* 25 mm  
  *Length:* 116 cm  
  *Height from ground level:* 99 cm

---

**Key plan**

**Hole direction**

**Videoendoscopic execution**

**Metrical Scale**

**Depth Scale**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone

---

**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

---

**Photo frames extracted from video**

- **Depth 0 cm (hole start)**
- **Depth 10 cm**
- **Depth 20 cm**
- **Depth 30 cm**
- **Depth 40 cm**
- **Depth 50 cm**
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 116 cm (inspection end)
2.15. VIDEOENDOSCOPY V-14

**Structural element:** masonry  
**Hole:** horizontal direction  
**Diameter:** 25 mm  
**Length:** 119 cm  
**Height from ground level:** 95 cm

[Key plan and hole direction diagram]

**Videoendoscopic execution**

**Ht = 95 cm**

---

**KEY OF SYMBOLS**
- Sandstone
- Mortar
- Limestone
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHEta
STRUCTURAL INVESTIGATIONS

* Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
2.16. VIDEOENDOSCOPY V-15

Structural element: masonry

Hole: horizontal direction

Diameter: 25 mm
Length: 117 cm
Height from ground level: 97 cm

Videoendoscopic execution

Key plan

Hole direction

Metrical Scale

Depth Scale

KEY OF SYMBOLS

- Sandstone
- Mortar
- Limestone
- Cavity
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)  
Depth 10 cm

Depth 20 cm  
Depth 30 cm

Depth 40 cm (cavity)  
Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 117 cm (inspection end)
2.17. VIDEOENDOSCOPY V-16

Structural element: pillar

Hole: horizontal direction

Diameter: 25 mm
Length: 117 cm
Height from ground level: 95 cm

Videoendoscopic execution

Key plan

Hole direction

Metrical Scale

Depth Scale

KEY OF SYMBOLS

Sandstone
Mortar
Limestone
Object: 

CATHEDRAL OF SVETITSHOVELI - MTSKHETA 

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  
Depth 10 cm  
Depth 20 cm  
Depth 30 cm  
Depth 40 cm  
Depth 50 cm
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 117 cm (inspection end)
2.18. VIDEOENDOSCOPY V-17

*Structural element:* pillar

*Hole:* horizontal direction

* Diameter: 25 mm
* Length: 96 cm
* Height from ground level: 97 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60

Depth 70

Depth 80

Depth 90

Depth 97 cm (inspection end)
2.19. **VIDEOENDOSCOPY V-18**

**Structural element:** pillar  
**Hole:** horizontal direction  
*Diameter:* 25 mm  
*Length:* 117 cm  
*Height from ground level:* 104 cm

---

**Videoendoscopic execution**

---

**Key plan**

---

**Hole direction**

---

**Metrical Scale**

---

**Depth Scale**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
CATHEDRAL OF SVETITSKHOVELI - MTSKHEТА
STRUCTURAL INVESTIGATIONS

Object:

Depth 60

Depth 70

Depth 80

Depth 90

Depth 100 cm

Depth 117 cm (inspection end)
2.20. VIDEOENDOSCOPY V-19

**Structural element:** pillar

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 86 cm
- Height from ground level: 112 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

<table>
<thead>
<tr>
<th>86</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
<th>0</th>
</tr>
</thead>
</table>

**Depth Scale**

**KEY OF SYMBOLS**

- **Sandstone**
- **Mortar**
- **Limestone**
- **Cavity**
**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

**STRUCTURAL INVESTIGATIONS**

**Photo frames extracted from video**

- **Depth 0 cm (hole start)**
- **Depth 10 cm**
- **Depth 20 cm**
- **Depth 30 cm**
- **Depth 40 cm**
- **Depth 50 cm**
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 86 cm (inspection end)
2.21. VIDEOENDOSCOPY V-20

**Structural element:** pillar

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 115 cm
- Height from pavement level: 110 cm

*Videoendoscopic execution*

*Key plan*

*Hole direction*

*KEY OF SYMBOLS*

- Sandstone
- Mortar
- Limestone
- Ophicalcite
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
**OBJECT:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

**STRUCTURAL INVESTIGATIONS**

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 115 cm (inspection end)
2.22. VIDEOENDOSCOPY V-21

**Structural element:** pillar

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 95 cm
- Height from pavement level: 68 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 95 cm (inspection end)
### 2.23. VIDEOENDOSCOPY V-22

**Structural element:** masonry  
**Hole:** horizontal direction  
  - Diameter: 25 mm  
  - Length: 117 cm  
  - Height from pavement level: 66 cm

![Videoendoscopic execution](image)

**Key plan**

<table>
<thead>
<tr>
<th>117</th>
<th>110</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
<th>0</th>
</tr>
</thead>
</table>

**Hole direction**

**Metadata:**
- **Videoendoscopic execution**
- **Ht = 68 cm**

**KEY OF SYMBOLS**
- **Sandstone**
- **Mortar**
- **Limestone**
- **Cavity**
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 12 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 117 cm (inspection end)
2.24. VIDEOENDOSCOPY V-23

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 114 cm
- **Height from pavement level:** 60 cm

*Videoendoscopic execution*

*Key plan*

*Hole direction*

**KEY OF SYMBOLS**

- Sandstone
- Mortar
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations via della Fonte di Fauno 2A - Tel +39-06-5746335 +39-06-5747860 Fax +39-06-5781268
2.25. **VIDEOENDOSCOPY V-24**

**Structural element:** pillar  
**Hole:** horizontal direction  
- Diameter: 25 mm  
- Length: 116 cm  
- Height from pavement level: 89 cm

![Image of structural element and hole direction]

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 116 cm (inspection end)
**2.26. VIDEOENDOSCOPY V-25**

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 110 cm
- **Height from pavement level:** 83 cm

---

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 60 cm
**Object:**
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

---

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm (inspection end)
2.27. **Videoendoscopy V-26**

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 117 cm
- **Height from pavement level:** 93 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
Object:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 117 cm (inspection end)
2.28. VIDEOENDOSCOPY V-27

**Structural element:** masonry

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 120 cm
- **Height from pavement level:** 90 cm

*Videoendoscopic execution*

**Key plan**

*Hole direction*

<table>
<thead>
<tr>
<th>Metrical Scale</th>
<th>Depth Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 110 100 90 80 70 60 50 40 30 20 10 0</td>
<td>0 10 20 30 40 50 60 70 80 90 100 110 120</td>
</tr>
</tbody>
</table>

**KEY OF SYMBOLS**
- **Sandstone**
- **Mortar**
- **Limestone**
Objective:

CATHEDRAL OF SVETITSHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 60 cm
Object:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 120 cm (inspection end)
2.29. VIDEOENDOSCOPY V-28

**Structural element:** masonry

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 117 cm
- **Height from ground level:** 130 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

- **Ht:** 130 cm

**Key of Symbols**

- Sandstone
- Mortar
- Cavity
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 117 cm (inspection end)
2.30. **VIDEOENDOSCOPY V-29**

**Structural element:** masonry  
**Hole:** horizontal direction

- **Diameter:** 25 mm  
- **Length:** 101 cm  
- **Height from ground level:** 116 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
- Ophialcite
Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
Object: CATHEDRAL OF SVETITSKOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 101 cm (inspection end)
2.31. VIDEOENDOSCOPY V-30

**Structural element:** masonry

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 116 cm
- Height from ground level: 59 cm

*Videoendoscopic execution*

**Key plan**

**Hole direction**

<table>
<thead>
<tr>
<th>Metrical Scale</th>
<th>Depth Scale</th>
</tr>
</thead>
</table>

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
- Opalcalcite
Photo frames extracted from video

Depth 0 cm (hole start)  
Depth 10 cm  
Depth 20 cm  
Depth 30 cm  
Depth 40 cm  
Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 117 cm (inspection end)
2.32. VIDEOENDOSCOPY V-31

**Structural element:** masonry

**Hole:** horizontal direction

* Diameter: 25 mm
* Length: 116 cm
* Height from ground level: 67 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Cavity
- Ophicalcite
Object: CATHEDRAL OF Svetitskhoveli - Mtskheta

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)  Depth 10 cm

Depth 20 cm  Depth 30 cm

Depth 40 cm  Depth 50 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 116 cm (inspection end)
2.33. VIDEOENDOSCOPY V-32

**Structural element:** masonry

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 67 cm
- Height from ground level: 80 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 50 cm

Depth 67 cm (inspection end)
2.34. VIDEOENDOSCOPY V-33

**Structural element:** masonry

**Hole:** horizontal direction

- Diameter: 25 mm
- Length: 113 cm
- Height from ground level: 90 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Ophicalcite
**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

**Photo frames extracted from video**

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 113 cm (inspection end)
2.35. **VIDEOENDOSCOPY V-34**

**Structural element:** masonry  
**Hole:** horizontal direction  
- Diameter: 25 mm  
- Length: 58 cm  
- Height from ground level: 65 cm  

![Image of a person using a videoendoscope]

**Videoendoscopic execution**

![Key plan and Hole direction diagrams]

**Key plan**

**Hole direction**

![Metrical Scale and Depth Scale]

**KEY OF SYMBOLS**
- Sandstone  
- Mortar  
- Ophicalcite
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKhetA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 58 cm (inspection end)
2.36. VIDEOENDOSCOPY V-35

*Structural element:* masonry

*Hole:* horizontal direction

-Diameter: 25 mm
-Length: 116 cm
-Height from ground level: 99 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

1. **Structural element:** masonry
2. **Hole:** horizontal direction
3. **Diameter:** 25 mm
4. **Length:** 116 cm
5. **Height from ground level:** 99 cm
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  
Depth 10 cm

Depth 20 cm  
Depth 30 cm

Depth 40 cm  
Depth 50 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 116 cm (inspection end)
2.37. VIDEOENDOSCOPY V-36

**Structural element:** masonry

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 116 cm
- **Height from ground level:** 37 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Ophicalcite
- Limestone
**Photo frames extracted from video**

- **Depth 0 cm (hole start)**
- **Depth 10 cm**
- **Depth 20 cm**
- **Depth 30 cm**
- **Depth 40 cm**
- **Depth 50 cm**
OBJECT: CATHEDRAL OF SVEITSHKOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 116 cm (inspection end)
2.38. VIDEOENDOSCOPY V-37

Structural element: masonry

Hole: horizontal direction

Diameter: 25 mm
Length: 95 cm
Height from pavement first floor: 90 cm

Videoendoscopic execution

Key plan

Hole direction

KEY OF SYMBOLS

Sandstone
Mortar
Object: CATHEDRAL OF SVETITSKOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Depth 60 cm

Depth 70 cm

Depth 80 cm

Depth 95 cm (inspection end)
2.39. **VIDEOENDOSCOPY V-38**

*Structural element:* masonry

*Hole:* horizontal direction

- Diameter: 25 mm
- Length: 70 cm
- Height from pavement first floor: 84 cm

*Videoendoscopic execution*

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)  
Depth 10 cm

Depth 30 cm  
Depth 50 cm

Depth 60 cm  
Depth 74cm (inspection end)
2.40. VIDEOENDOSCOPY V-39

Structural element: pillar

Hole: horizontal direction

Diameter: 25 mm
Length: 74 cm
Height from pavement first floor: 153 cm
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)    Depth 10 cm

Depth 30 cm    Depth 50 cm

Depth 60 cm    Depth 70 cm (inspection end)
2.41. VIDEOENDOSCOPY V-40

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 118 cm
- **Height from pavement level:** 656 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 118 cm (inspection end)
2.42. **VIDEOENDOSCOPY V-41**

**Structural element:** pillar  
**Hole:** horizontal direction  
  *Diameter:* 25 mm  
  *Length:* 115 cm  
  *Height from pavement level:* 635 cm

---

**Videoendoscopic execution**

---

**Key plan**

---

**Hole direction**

---

**Metrical Scale**

---

**Depth Scale**

---

**KEY OF SYMBOLS**

- Sandstone
- Mortar
- Limestone
- Ophicalcite
Object: CATHEDRAL OF SVETITSHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 114 cm (inspection end)
2.43. VIDEOENDOSCOPY V-42

**Structural element:** pillar

**Hole:** horizontal direction

- **Diameter:** 25 mm
- **Length:** 117 cm
- **Height from pavement level:** 628 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Metrical Scale**

**Depth Scale**

**Key of Symbols**

- Sandstone
- Mortar
- Limestone
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
Object:
Cathedral of Svetitskhoveli - Mtskheta
Structural Investigations
2.44. VIDEOENDOSCOPY V-43

**Structural element:** pillar  
**Hole:** horizontal direction  
**Diameter:** 25 mm  
**Length:** 118 cm  
**Height from pavement level:** 646 cm

![Videoendoscopic execution](image)

![Key plan](image)

![Hole direction](image)

**KEY OF SYMBOLS**
- Sandstone
- Mortar
- Limestone
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Structural Investigations

Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 60 cm
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Depth 70 cm

Depth 80 cm

Depth 90 cm

Depth 100 cm

Depth 110 cm

Depth 118 cm (inspection end)
2.45. VIDEOENDOSCOPY V-44

**Structural element:** pillar  
**Hole:** horizontal direction  
\[ \text{Diameter: } 25 \text{ mm} \]  
\[ \text{Length: } 54 \text{ cm} \]  
\[ \text{Height from pavement level: } 643 \text{ cm} \]

**Videoendoscopic execution**  

**Key plan**  
**Hole direction**  

**Metrical Scale**  
**Depth Scale**

**KEY OF SYMBOLS**  
- Sandstone  
- Mortar  
- Limestone
**Object:**

CATHEDRAL OF SVETITSHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

**Photo frames extracted from video**

Depth 0 cm (hole start)  
Depth 10 cm  
Depth 20 cm  
Depth 30 cm  
Depth 40 cm  
Depth 54 cm (inspection end)
2.46. VIDEOENDOSCOPY V-45

**Structural element:** vault

**Hole:** vertical direction

- **Diameter:** 25 mm
- **Length:** 100 cm
- **Height from pavement level:** 782 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Stone vault**

**W-View**

- niche
- roof (c) = 875 cm
- (s) = 840 cm

**S-View**

- roof (c) = 875 cm
- (s) = 640 cm

**E-View**

- roof
- aperture
- arc (o) = 876 cm
- (s) = 640 cm
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm

Depth 50 cm
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations via della Fonte di Fauno 2A
Tel +39-06-5746335 +39-06-5747860 Fax +39-06-5781268

Depth 60 cm

Depth 70 cm (End vault)

Niche

Roof

Aperture and niche
2.47. VIDEOENDOSCOPY V-46

**Structural element:** vault

**Hole:** vertical direction
- Diameter: 25 mm
- Length: 50 cm
- Height from pavement level: 776 cm

**Videoendoscopic execution**

**Key plan**

**Hole direction**

**Brick vault**

- **W-View**
  - (c) = 886 cm
  - (s) = 575 cm

- **N-View**
  - (c) = 886 cm
  - (s) = 575 cm

- **E-View**
  - (c) = 886 cm
  - (s) = 575 cm
Photo frames extracted from video

Depth 0 cm (hole start)

Depth 10 cm

Depth 20 cm

Depth 30 cm

Depth 40 cm (End vault)

Niche
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Aperture

Niche

Aperture

Roof
3. SONIC TESTS

The sonic tests have been done by a technique called "by transparency" with the purpose to know the propagation speed of the longitudinal waves through the walls. Through these parameters it is possible to make some comparative estimates of the degrade state and masonries homogeneity. In general, it is not possible to make analytic comparison between the modulus of elasticity and the material resistance, because there is dispersion of the signal during the test.

Through the percentage ratio between the standard deviation (σ) and the middle speed (Vm), we can get an index that allow to evaluate the uniformity of the speed through the structural element. Comparing the index with a reference value (7÷10%), tolerating the errors of measure and the possible variations in the masonry, we have a real evaluation in the masonry, and of the uniformity in the site investigation.

In general, very high values of σ/Vm indicate lesions in the masonry, and lack of homogeneity.

For the execution of the sonic tests, a sampling instrumentation in real time able to visualize on the laptop's monitor the wave form and getting the signals coming from the sensors has been used.

The used instrumentation has the following technical characteristics:

Laptop computer: model ASUS US
microprocessor CPU-M750
hard dish 80 Gb

Acquisition card: 16 canal acquisition
resolution 12 bit
conversation time 20 μs
direct transfer in memory (DMA)
speed of sampling 83 KHz

Forms of signal conditioning:
gain regulation (1-10-100) for any canal
supply of the tools with stabilized tension
adjustable filter pass-low and pass-high

Acceleration sensors: model IC - piezoresistive sensor
sensitivity 1 Volt/g
deep scale: ± 5 g
answered in linear frequency in the field 0 ÷ 1000 Hz

Connection cables: coaxial type RG58
The setting system has been effected in order to know the hardware configuration and optimal software for the wave correct recording. A good definition about the parameters of acquisition, allows to have a sufficient number of points for the determination of the elastic wave propagation speed; in the phase of elaboration of the signal. The parameters of acquisition chosen are:

- amplification of the signal effected by the modulus of conditioning of the signal: 1
- gain regulation by software: 1
- deep scale graphic: ±0.005 ±0.01g

Every measure has been made positioning the piezoelectric transmitter on a wall and the receiver on the opposite side. Knowing the distance "d" between receiver and transmitter we get the sonic wave's speed propagation through the walls (d/t).

The analytic results are showed through charts and graphics. In the graphic representation we use a chromatic scale for showing the values of the recorded speeds in the nodes of the network giving an immediate possibility to know uniformity of the mechanical characteristics in the wall.
3.1. **Location of the Sonic Tests**

[Diagram of the cathedral with labeled locations for sonic tests]
3.2. **Sonic Test S-1**

**SONIC TEST S1**

<table>
<thead>
<tr>
<th>DATE:</th>
<th>08/11/2012</th>
<th>FLOOR:</th>
<th>ground level</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION:</td>
<td>Mtskheta - Georgia</td>
<td>ELEMENT:</td>
<td>pillar</td>
</tr>
<tr>
<td>SITE:</td>
<td>Cathedral of Svetskhoveli</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PLASTERED WALLS**

<table>
<thead>
<tr>
<th>INSIDE</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTSIDE</td>
<td>NO</td>
</tr>
</tbody>
</table>

**CONSOLIDATED WALL**

<table>
<thead>
<tr>
<th>THICKNESS OF THE WALL (cm)</th>
<th>307</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID POINTS (cm x cm)</td>
<td>20 x 20</td>
</tr>
</tbody>
</table>

**WAVE DIRECTION OUTWARD**

<table>
<thead>
<tr>
<th>Generated n°</th>
<th>Received n°</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.65</td>
<td>1861</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.62</td>
<td>1897</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1.66</td>
<td>1849</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1.43</td>
<td>2146</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1.69</td>
<td>1815</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1.49</td>
<td>2056</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.37</td>
<td>2244</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.38</td>
<td>2227</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1.21</td>
<td>2535</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1.46</td>
<td>2100</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>1.43</td>
<td>2146</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>1.39</td>
<td>2211</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>1.24</td>
<td>2471</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>1.35</td>
<td>2279</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>1.37</td>
<td>2244</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>1.24</td>
<td>2471</td>
</tr>
</tbody>
</table>

**SITE NOTE**

- **Vm** (m/s): 2159
- **σ** (m/s): 217
- **σ / Vm (%)**: 10.1

H = 76 cm
CHROMATIC PLOT OF SPEED

OXIS:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS
3.3. **Sonic Test S-2**

### SONIC TEST S2

**DATE:** 08/11/2012  
**FLOOR:** ground level  
**LOCATION:** Mtskheta - Georgia  
**ELEMENT:** pillar  
**SITE:** Cathedral of Svetskhoveli  

<table>
<thead>
<tr>
<th>PLASTERED WALLS</th>
<th>CONSOLIDATED WALL</th>
<th>NO</th>
<th>THICKNESS OF THE WALL (cm)</th>
<th>275</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSIDE</td>
<td></td>
<td>NO</td>
<td>GRID POINTS (cm x cm)</td>
<td>20 x 20</td>
</tr>
<tr>
<td>OUTSIDE</td>
<td></td>
<td>NO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**WAVE DIRECTION OUTWARD**

<table>
<thead>
<tr>
<th>Generated n°</th>
<th>Received n°</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2,38</td>
<td>1155</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2,97</td>
<td>927</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2,54</td>
<td>1084</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>3,09</td>
<td>890</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>3,02</td>
<td>911</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>3,01</td>
<td>915</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>2,83</td>
<td>972</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>2,89</td>
<td>952</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>2,81</td>
<td>979</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>2,98</td>
<td>924</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>3,03</td>
<td>908</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>2,41</td>
<td>1140</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>2,52</td>
<td>1093</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>2,66</td>
<td>1033</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>2,86</td>
<td>961</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>2,32</td>
<td>1186</td>
</tr>
</tbody>
</table>

**SITE NOTE**

H = 65 cm

<table>
<thead>
<tr>
<th>Vm (m/s)</th>
<th>σ (m/s)</th>
<th>σ / Vm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001</td>
<td>95</td>
<td>9.5</td>
</tr>
</tbody>
</table>
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED
3.4. **Sonic Test S-3**

### SONIC TEST S3

<table>
<thead>
<tr>
<th>Date:</th>
<th>08/11/2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location:</td>
<td>Mtskheta - Georgia</td>
</tr>
<tr>
<td>Site:</td>
<td>Cathedral of Svetshoveli</td>
</tr>
<tr>
<td>Floor:</td>
<td>ground level</td>
</tr>
<tr>
<td>Element:</td>
<td>masonry</td>
</tr>
</tbody>
</table>

**Plastered Walls**
- Inside: No
- Outside: No

**Consolidated Wall**
- No

**Thickness of the Wall (cm)**: 133

**Grid Points (cm x cm)**: 20 x 20

<table>
<thead>
<tr>
<th>Wave Direction</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTWARD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2,17</td>
<td>614</td>
</tr>
<tr>
<td>2</td>
<td>1,79</td>
<td>745</td>
</tr>
<tr>
<td>3</td>
<td>1,81</td>
<td>736</td>
</tr>
<tr>
<td>4</td>
<td>1,93</td>
<td>689</td>
</tr>
<tr>
<td>5</td>
<td>1,73</td>
<td>767</td>
</tr>
<tr>
<td>6</td>
<td>1,64</td>
<td>811</td>
</tr>
<tr>
<td>7</td>
<td>1,90</td>
<td>700</td>
</tr>
<tr>
<td>8</td>
<td>2,11</td>
<td>631</td>
</tr>
<tr>
<td>9</td>
<td>1,85</td>
<td>720</td>
</tr>
<tr>
<td>10</td>
<td>1,75</td>
<td>758</td>
</tr>
<tr>
<td>11</td>
<td>1,48</td>
<td>897</td>
</tr>
<tr>
<td>12</td>
<td>1,62</td>
<td>822</td>
</tr>
<tr>
<td>13</td>
<td>1,58</td>
<td>844</td>
</tr>
<tr>
<td>14</td>
<td>1,63</td>
<td>817</td>
</tr>
<tr>
<td>15</td>
<td>1,60</td>
<td>833</td>
</tr>
<tr>
<td>16</td>
<td>1,56</td>
<td>855</td>
</tr>
</tbody>
</table>

**SITE NOTE**

**WAVE DIRECTION**
- OUTWARD

**Vm (m/s)**: 764
**σ (m/s)**: 78
**σ / Vm (%)**: 10.2
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED
### 3.5. **Sonic Test S-4**

**Sonic Test S4**

<table>
<thead>
<tr>
<th><strong>DATE:</strong></th>
<th>08/11/2012</th>
<th><strong>FLOOR:</strong></th>
<th>ground level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOCATION:</strong></td>
<td>Mtskheta - Georgia</td>
<td><strong>ELEMENT:</strong></td>
<td>pillar</td>
</tr>
<tr>
<td><strong>SITE:</strong></td>
<td>Cathedral of Svettskhoveli</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Plastered Walls**

<table>
<thead>
<tr>
<th>INSIDE</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTSIDE</td>
<td>NO</td>
</tr>
</tbody>
</table>

**Consolidated Wall**

| **THICKNESS OF THE WALL (cm)** | 234 |
| **GRID POINTS (cm x cm)** | 20 x 20 |

**Wave Direction Outward**

<table>
<thead>
<tr>
<th>Generated n°</th>
<th>Received n°</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.83</td>
<td>1281</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.72</td>
<td>1358</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2.19</td>
<td>1067</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1.83</td>
<td>1281</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1.58</td>
<td>1478</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1.51</td>
<td>1546</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.14</td>
<td>2056</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.45</td>
<td>1612</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1.65</td>
<td>1418</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1.36</td>
<td>1724</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>1.19</td>
<td>1966</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>1.51</td>
<td>1546</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>1.83</td>
<td>1281</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>1.51</td>
<td>1546</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>1.37</td>
<td>1711</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>1.28</td>
<td>1822</td>
</tr>
</tbody>
</table>

**Site Note**

- H = 70 cm

![](image1.png)

<table>
<thead>
<tr>
<th>Vm (m/s)</th>
<th>σ (m/s)</th>
<th>σ / Vm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1543</td>
<td>258</td>
<td>16.7</td>
</tr>
</tbody>
</table>
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED
3.6. **Sonic Test S-5**

### Sonic Test S5

<table>
<thead>
<tr>
<th>DATE:</th>
<th>08/11/2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION:</td>
<td>Mtskheta - Georgia</td>
</tr>
<tr>
<td>SITE:</td>
<td>Cathedral of Svetitskhoveli</td>
</tr>
<tr>
<td>FLOOR:</td>
<td>ground level</td>
</tr>
<tr>
<td>ELEMENT:</td>
<td>masonry</td>
</tr>
</tbody>
</table>

#### Plastered Walls

<table>
<thead>
<tr>
<th>INSIDE</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTSIDE</td>
<td>NO</td>
</tr>
</tbody>
</table>

#### Consolidated Wall

<table>
<thead>
<tr>
<th>THICKNESS OF THE WALL (cm)</th>
<th>137</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRID POINTS (cm x cm)</td>
<td>20 x 20</td>
</tr>
</tbody>
</table>

#### Wavelengths Direction

<table>
<thead>
<tr>
<th>Generated</th>
<th>Received</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n°</td>
<td>n°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1.47</td>
<td>929</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1.38</td>
<td>994</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1.32</td>
<td>1041</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1.86</td>
<td>737</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1.15</td>
<td>1193</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1.01</td>
<td>1353</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.76</td>
<td>779</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.69</td>
<td>810</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1.05</td>
<td>1299</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1.06</td>
<td>1286</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>1.29</td>
<td>1058</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>1.20</td>
<td>1141</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>1.08</td>
<td>1274</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>1.39</td>
<td>987</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>1.40</td>
<td>979</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>1.47</td>
<td>931</td>
</tr>
</tbody>
</table>

#### Site Note

- **WAVE DIRECTION OUTWARD**
- **Vm (m/s)**
- **\( \sigma \) (m/s)**
- **\( \sigma / Vm \) (%)**

<table>
<thead>
<tr>
<th>Vm (m/s)</th>
<th>( \sigma ) (m/s)</th>
<th>( \sigma / Vm ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1049</td>
<td>186</td>
<td>17.7</td>
</tr>
</tbody>
</table>

**H = 50 cm**
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED

speed (m/s)
3.7. **Sonic Test S-6**

**Sonic Test S6**

**Date:** 08/11/2012  
**Floor:** ground level  
**Location:** Mtskheta - Georgia  
**Element:** masonry  
**Site:** Cathedral of Svetskhoveli

**Plastered Walls**

<table>
<thead>
<tr>
<th></th>
<th>Inside</th>
<th>Outside</th>
<th>Inside</th>
<th>Outside</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inside</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Consolidated Wall**

- **Thickness of the Wall (cm):** 120  
- **Grid Points (cm x cm):** 20 x 20

**Wave Direction Outward**

<table>
<thead>
<tr>
<th>Generated n°</th>
<th>Received n°</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2.71</td>
<td>442</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3.15</td>
<td>381</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3.41</td>
<td>352</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1.85</td>
<td>649</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1.40</td>
<td>859</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>2.62</td>
<td>458</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.93</td>
<td>621</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>1.65</td>
<td>727</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>1.54</td>
<td>779</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>2.18</td>
<td>552</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>1.88</td>
<td>639</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>1.51</td>
<td>793</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>1.86</td>
<td>644</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>1.72</td>
<td>697</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>1.61</td>
<td>748</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>2.55</td>
<td>471</td>
</tr>
</tbody>
</table>

**Site Note**

![Image of a cathedral interior with a person examining a wall]

<table>
<thead>
<tr>
<th>Vm (m/s)</th>
<th>σ (m/s)</th>
<th>σ / Vm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>613</td>
<td>150</td>
<td>24.5</td>
</tr>
</tbody>
</table>
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED
3.8. **Sonic Test S-7**

### Sonic Test S7

<table>
<thead>
<tr>
<th>DATE:</th>
<th>08/11/2012</th>
<th>FLOOR:</th>
<th>ground level</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION:</td>
<td>Mtskheta - Georgia</td>
<td>ELEMENT:</td>
<td>pillar</td>
</tr>
<tr>
<td>SITE:</td>
<td>Cathedral of Svetitskhoveli</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Plastered Walls

<table>
<thead>
<tr>
<th>TYPE</th>
<th>INSIDE</th>
<th>OUTSIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consolidated Wall</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of the Wall (cm)</td>
<td>90</td>
</tr>
<tr>
<td>Grid Points (cm x cm)</td>
<td>20 x 20</td>
</tr>
</tbody>
</table>

#### Wave Direction

<table>
<thead>
<tr>
<th>n°</th>
<th>Generated</th>
<th>Received</th>
<th>Time (ms)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.49</td>
<td>1837</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.57</td>
<td>1574</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0.60</td>
<td>1500</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>4</td>
<td>0.53</td>
<td>1698</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.59</td>
<td>1519</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>6</td>
<td>0.75</td>
<td>1201</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>7</td>
<td>0.61</td>
<td>1467</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>8</td>
<td>0.69</td>
<td>1311</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>9</td>
<td>0.58</td>
<td>1552</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0.73</td>
<td>1236</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>11</td>
<td>0.69</td>
<td>1311</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>12</td>
<td>0.64</td>
<td>1396</td>
</tr>
<tr>
<td>13</td>
<td>13</td>
<td>13</td>
<td>0.72</td>
<td>1254</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>14</td>
<td>0.52</td>
<td>1731</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>15</td>
<td>0.51</td>
<td>1768</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>16</td>
<td>0.54</td>
<td>1665</td>
</tr>
</tbody>
</table>

#### Site Note

- **H = 132 cm**

<table>
<thead>
<tr>
<th>Vm (m/s)</th>
<th>σ (m/s)</th>
<th>σ / Vm (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1501</td>
<td>196</td>
<td>13,1</td>
</tr>
</tbody>
</table>
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

CHROMATIC PLOT OF SPEED
4. MINERALOGICAL ANALYSIS OF THE MORTAR

In order to characterize the mixture used as a binder in the walls of the Cathedral was taken a sample of mortar at the extrados of the vault on the ground floor, +10.10 m from ground level during the first mission in November 2012. Mineralogical analysis of the sample was carried out at the laboratories of Pro Arte s.n.c. specializing in this area. This kind of analysis allows the characterization of the matrix and to determine the typology and the composition of the aggregates, the type of the mixture and the state of preservation.

The photographic documentation of the sample and the results of the mineralogical analysis are hereinafter shown.
4.1. Sample 1

<table>
<thead>
<tr>
<th>Type of sampling:</th>
<th>Fragments of mortar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of sampling:</td>
<td>Extrados vault floor, +10.10 m from ground level</td>
</tr>
<tr>
<td>Scope of tests:</td>
<td>Characterization of the mixture</td>
</tr>
<tr>
<td>Type of analysis:</td>
<td>Mineralogical-petrographical analysis</td>
</tr>
</tbody>
</table>

Mineralogical-petrographical analysis

**Macroscopic description (UNI-NORMAL 12/83)**

<table>
<thead>
<tr>
<th>Dimensional aspect</th>
<th>Conglomeratic-arenaceo-siltoso</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Gray</td>
</tr>
<tr>
<td>Cohesion</td>
<td>Medium to high tough and cohesive</td>
</tr>
</tbody>
</table>

**Microscopic description (UNI-NORMAL 12/83)**

**Aggregate**

<table>
<thead>
<tr>
<th>Granulometry</th>
<th>Microconglomeratic (4-2 mm) – coarse siltoso (0.062-0.032 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometria prevalente</td>
<td>Medium-coarse arenaceo (1-0.25 mm).</td>
</tr>
<tr>
<td>Class</td>
<td>Medium class</td>
</tr>
<tr>
<td>Shape</td>
<td>Medium to low sphericity / Sharp to rounded fragments</td>
</tr>
<tr>
<td>(sphericity/rounding)</td>
<td></td>
</tr>
<tr>
<td>Superficial Morphology</td>
<td>Smooth to abrasive</td>
</tr>
<tr>
<td>Orientation</td>
<td>Not detected</td>
</tr>
<tr>
<td>Distribution</td>
<td>Omogeneous</td>
</tr>
<tr>
<td>Packing</td>
<td>Clasti-matrice ratio estimation: very high (45%)</td>
</tr>
</tbody>
</table>
**Granulometric distribution**

<table>
<thead>
<tr>
<th>Granulometric class</th>
<th>mm</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microconglomeratic</td>
<td>4-2</td>
<td>7</td>
</tr>
<tr>
<td>Highly coarse <em>arenacea</em></td>
<td>2-1</td>
<td>6</td>
</tr>
<tr>
<td>Coarse <em>arenacea</em></td>
<td>1-0.5</td>
<td>21</td>
</tr>
<tr>
<td>Medium <em>arenacea</em></td>
<td>0.5-0.25</td>
<td>32</td>
</tr>
<tr>
<td>Fine <em>arenacea</em></td>
<td>0.25-0.125</td>
<td>24</td>
</tr>
<tr>
<td>Highly fine <em>arenacea</em></td>
<td>0.125-0.062</td>
<td>8</td>
</tr>
<tr>
<td><em>Siltosa</em></td>
<td>&lt; 0.062</td>
<td>2</td>
</tr>
</tbody>
</table>

**Composition of the aggregates**
- 71%: fragments of carbonatic stones such as *micritici* limestones, loamy limestones, polycrystalline *calcite, arenacei* limestones
- 21%: fragments of mono and polycrystalline quartz
- 4%: iron oxides
- 2%: fragments of *feldspati geminati*
- 2%: fragments of pebble

Type of aggregate: fluvial sand, mainly silicatic and for about 1/5 carbonatic.

**Porosity**

<table>
<thead>
<tr>
<th>Pores Ratio</th>
<th>Medium (21 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity origin</td>
<td>Both primary and secondary</td>
</tr>
<tr>
<td>Shape of pores</td>
<td>Irregular blisters and vacuity due to binder, with some rare micro crack</td>
</tr>
</tbody>
</table>
Matrix

<table>
<thead>
<tr>
<th>Structure</th>
<th>Heterogeneous with some coarse calcinarolo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaving</td>
<td>From colloforme to micritica</td>
</tr>
<tr>
<td>Clasti/matrice ratio</td>
<td>Not determined</td>
</tr>
<tr>
<td>Composition</td>
<td>Carbonatatic common lime</td>
</tr>
</tbody>
</table>

Considerations on the mixture

| Type of mixture                                                                 | Grey mixture obtained from the compound of common lime and mainly carbonatic and less silicatic fluvial sand composed by carbonatic fragments, quartz, iron oxides, feldspati and pebble. The range of the size of the aggregates is 2.6 mm - 0.04 mm, with the main portion constituted by medium arenacea. The areal ratio between aggregates and binder is evaluable to values closer to 3.5/1. The mixture points out a both primary and secondary porosity. |
| State of preservation                                                        | The mixture appears sufficiently preserved |
Mixture constituted by common lime and mainly carbonatic and less silicatic fluvial sand. The binder/aggregate ratio is evaluable to values closer to 3.5/1. Thin section, transmitted light, 40 X, N+

Other picture of the same mixture where some carbonatic and silicatic minerals which are part of the inert utilized in the mixture are underlined. Thin section, transmitted light, 40 X, N+
5. MECHANICAL LABORATORY TESTS

The samples collected at the Svetitskhoveli Cathedral during the first mission in November 2012 were tested in laboratory in order to get information about the mechanical characteristics of the materials constituting the walls.

28 prismatic specimens were obtained cutting the samples and adequately geometrizing the load faces; 22 of them subject to compression tests for the determination of the ultimate compressive load and 6 subject to compression tests for the determination of the elastic modulus and the ultimate compressive load.

The specimens 1-I, 1-III, 4-I, 4-IV and 7-II were tested after 24 hours of water saturation; all the others were tested after drying.

The tests have been carried out using a hydraulic machine MTS, with full scales of 50 kN and 500 kN. The strain values were obtained using electric strain gages conditioned by a module National Instruments NI-9327 while the load was determined with the load cell of the testing machine.

The photographic documentation of the specimens and the results of the compression tests are hereinafter shown.
## 5.1. Results

<table>
<thead>
<tr>
<th>SPECIMEN 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image I" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Image III" /></td>
</tr>
<tr>
<td><img src="image5.png" alt="Image V" /></td>
</tr>
</tbody>
</table>
### SPECIMEN 2

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image 1" /></td>
<td><img src="image2" alt="Image 2" /></td>
</tr>
</tbody>
</table>

### SPECIMEN 3

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Image 3" /></td>
<td><img src="image4" alt="Image 4" /></td>
<td><img src="image5" alt="Image 5" /></td>
<td><img src="image6" alt="Image 6" /></td>
</tr>
</tbody>
</table>
SPECIMEN 4

I

II

III

IV

V
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

SPECIMEN 5A

SPECIMEN 5B

SPECIMEN 6
<table>
<thead>
<tr>
<th>Specimen 7</th>
<th>Specimen 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image 1" /></td>
<td><img src="image2.png" alt="Image 2" /></td>
</tr>
<tr>
<td><img src="image3.png" alt="Image 3" /></td>
<td><img src="image4.png" alt="Image 4" /></td>
</tr>
<tr>
<td><img src="image5.png" alt="Image 5" /></td>
<td><img src="image6.png" alt="Image 6" /></td>
</tr>
<tr>
<td><img src="image7.png" alt="Image 7" /></td>
<td><img src="image8.png" alt="Image 8" /></td>
</tr>
</tbody>
</table>

**OBJECT:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

**STRUCTURAL INVESTIGATIONS**
## Object:

**CATHEDRAL OF SVETITSKHOVELI - MTSKHETA**

**STRUCTURAL INVESTIGATIONS**

<table>
<thead>
<tr>
<th>Sample / Specimen</th>
<th>Type</th>
<th>R/C</th>
<th>Height [mm]</th>
<th>Base [mm]</th>
<th>Density dry [kg/m²]</th>
<th>Saturated [kg/m²]</th>
<th>Ultimate tension [MPa]</th>
<th>Elastic Modulus range [MPa]</th>
<th>Elastic Modulus value [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>sandstone</td>
<td>I</td>
<td>59</td>
<td>58</td>
<td>2055</td>
<td>2168</td>
<td>17.84</td>
<td>4.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>56</td>
<td>59</td>
<td>2070</td>
<td></td>
<td>34.54</td>
<td>4.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>III</td>
<td>41</td>
<td>40</td>
<td>2037</td>
<td>2160</td>
<td>19.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IV</td>
<td>49</td>
<td>49</td>
<td>2108</td>
<td></td>
<td>17.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>41</td>
<td>40</td>
<td>2063</td>
<td></td>
<td>19.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>brick</td>
<td>I</td>
<td>49</td>
<td>51</td>
<td>1739</td>
<td></td>
<td>8.58</td>
<td>2.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>49</td>
<td>49</td>
<td>1742</td>
<td></td>
<td>6.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>black limestone</td>
<td>I</td>
<td>52</td>
<td>51</td>
<td>2654</td>
<td></td>
<td>186.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>52</td>
<td>51</td>
<td>2640</td>
<td></td>
<td>186.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>III</td>
<td>50</td>
<td>51</td>
<td>2643</td>
<td></td>
<td>70.44 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IV</td>
<td>39</td>
<td>39</td>
<td>2699</td>
<td></td>
<td>199.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>sandstone</td>
<td>I</td>
<td>50</td>
<td>52</td>
<td>2465</td>
<td>2504</td>
<td>63.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>51</td>
<td>50</td>
<td>2527</td>
<td></td>
<td>84.34</td>
<td>23.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>III</td>
<td>44</td>
<td>42</td>
<td>2371</td>
<td></td>
<td>38.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>IV</td>
<td>43</td>
<td>43</td>
<td>2469</td>
<td>2520</td>
<td>38.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>44</td>
<td>43</td>
<td>2525</td>
<td></td>
<td>64.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>brick</td>
<td>I</td>
<td>47</td>
<td>49</td>
<td>1860</td>
<td></td>
<td>26.69</td>
<td>17.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>46</td>
<td>49</td>
<td>1785</td>
<td></td>
<td>30.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>brick</td>
<td>I</td>
<td>40</td>
<td>41</td>
<td>1875</td>
<td></td>
<td>25.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>39</td>
<td>40</td>
<td>1720</td>
<td></td>
<td>13.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>brick</td>
<td>I</td>
<td>40</td>
<td>39</td>
<td>1836</td>
<td></td>
<td>34.44</td>
<td>11.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>37</td>
<td>39</td>
<td>1792</td>
<td></td>
<td>36.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>ophicalcite</td>
<td>I</td>
<td>44</td>
<td>45</td>
<td>1654</td>
<td></td>
<td>10.72</td>
<td>3.31</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>34</td>
<td>35</td>
<td>1631</td>
<td>1806</td>
<td>7.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>III</td>
<td>31</td>
<td>31</td>
<td>1645</td>
<td></td>
<td>8.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>mortar</td>
<td>I</td>
<td>33</td>
<td>34</td>
<td>1754</td>
<td></td>
<td>1.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>II</td>
<td>27</td>
<td>30</td>
<td>1738</td>
<td></td>
<td>1.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>III</td>
<td>19</td>
<td>21</td>
<td>1712</td>
<td></td>
<td>1.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: sample 3-III: rupture occurred along a pre-existing defect.*
5.2. **Test Certificate**

A questo Laboratorio sono pervenuti 9 campioni in materiale lapideo, laterizio e malta, tutti prelevati dal committente le prove.

Dai campioni, di seguito indicati come 1, 2, 3, 4, 5A, 5B, 6, 7 e 8 sono stati ricavati, mediante taglio e rettifica delle facce di carico, 28 provini prismatici dei quali 22 da sottoporre a prova di compressione per la determinazione del carico di rottura e 6 da sottoporre a prova di compressione per la determinazione del modulo elastico e del carico di rottura.

I provini 1-I, 1-III, 4-I, 4-IV e 7-II sono stati provati previa saturazione in acqua per 24 ore; tutti gli altri sono stati provati previa essiccazione.

Tutte le prove sono state effettuate con una macchina oleodinamica MTS, con fondi scala 50 kN e 500 kN. I valori delle deformazioni sono stati ricavati tramite estensimetri elettrici condizionati con un modulo National Instruments NI-9237, mentre il carico è stato ricavato utilizzando la cella di carico della macchina di prova. L’hardware è stato gestito tramite software LabVIEW prodotto dalla stessa casa.

In Tabella 1 sono riportati dati geometrici, tipologia dei provini e le risultanze delle prove di compressione.
## Tabella 1: Risultati delle prove (data di prova 10-18 gennaio 2013)

<table>
<thead>
<tr>
<th>Campione /Provincia</th>
<th>Tipo (1)</th>
<th>Altezza (mm)</th>
<th>Base (mm)</th>
<th>Densità asciutta (kg/m³)</th>
<th>Tensione di rottura (MPa)</th>
<th>Modulo elastico (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>pietra arenaria</td>
<td>59</td>
<td>58</td>
<td>58</td>
<td>2055</td>
<td>2168</td>
</tr>
<tr>
<td>II</td>
<td>pietra arenaria</td>
<td>56</td>
<td>59</td>
<td>56</td>
<td>2070</td>
<td>34.54</td>
</tr>
<tr>
<td>III</td>
<td>pietra arenaria</td>
<td>41</td>
<td>40</td>
<td>40</td>
<td>2037</td>
<td>2190</td>
</tr>
<tr>
<td>IV</td>
<td>pietra arenaria</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>2108</td>
<td>17.23</td>
</tr>
<tr>
<td>V</td>
<td>pietra arenaria</td>
<td>41</td>
<td>40</td>
<td>41</td>
<td>2063</td>
<td>19.06</td>
</tr>
<tr>
<td>II</td>
<td>laterizio</td>
<td>49</td>
<td>51</td>
<td>52</td>
<td>1739</td>
<td>6.88</td>
</tr>
<tr>
<td>III</td>
<td>laterizio</td>
<td>52</td>
<td>51</td>
<td>51</td>
<td>2654</td>
<td>186.77</td>
</tr>
<tr>
<td>IV</td>
<td>laterizio</td>
<td>50</td>
<td>51</td>
<td>50</td>
<td>2043</td>
<td>186.51</td>
</tr>
<tr>
<td>V</td>
<td>laterizio</td>
<td>39</td>
<td>39</td>
<td>38</td>
<td>2699</td>
<td>199.27</td>
</tr>
<tr>
<td>II</td>
<td>pietra calcarea scura</td>
<td>50</td>
<td>52</td>
<td>50</td>
<td>2465</td>
<td>2504</td>
</tr>
<tr>
<td>III</td>
<td>pietra calcarea scura</td>
<td>51</td>
<td>50</td>
<td>50</td>
<td>2527</td>
<td>84.34</td>
</tr>
<tr>
<td>IV</td>
<td>pietra calcarea scura</td>
<td>44</td>
<td>42</td>
<td>42</td>
<td>2371</td>
<td>38.54</td>
</tr>
<tr>
<td>V</td>
<td>pietra calcarea scura</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>2469</td>
<td>38.47</td>
</tr>
<tr>
<td>II</td>
<td>laterizio</td>
<td>47</td>
<td>49</td>
<td>46</td>
<td>1860</td>
<td>26.69</td>
</tr>
<tr>
<td>III</td>
<td>laterizio</td>
<td>46</td>
<td>49</td>
<td>48</td>
<td>1785</td>
<td>30.45</td>
</tr>
<tr>
<td>IV</td>
<td>laterizio</td>
<td>40</td>
<td>41</td>
<td>42</td>
<td>1875</td>
<td>25.26</td>
</tr>
<tr>
<td>V</td>
<td>laterizio</td>
<td>39</td>
<td>40</td>
<td>40</td>
<td>1720</td>
<td>13.82</td>
</tr>
<tr>
<td>II</td>
<td>laterizio</td>
<td>40</td>
<td>39</td>
<td>37</td>
<td>1836</td>
<td>34.44</td>
</tr>
<tr>
<td>III</td>
<td>laterizio</td>
<td>37</td>
<td>39</td>
<td>38</td>
<td>1792</td>
<td>36.03</td>
</tr>
</tbody>
</table>

(1) dato fornito dal committente  
(2) $R =$ provino rettificato; $C =$ provino cappato  
(3) la rottura è avvenuta lungo un evidente difetto preesistente
6. MONITORING SYSTEM

6.1. TECHNICAL CHARACTERISTICS

6.1.1. Data Acquisition System

The installed datalogger is a fully programmable standalone data acquisition and control unit with non-volatile memory and a battery backed clock in a small, rugged, sealed module. It is housed in a waterproof enclosure with a power supply. The data acquisition system reads the output of a range of sensors and then digitizes, processes and stores the results, according to the given programming. Data can be retrieved to a PC locally or over a remote communication link.

The power supply is external and the system can be connected to any 12 V battery acting as a primary power source. A battery-backed clock keeps time while the datalogger is disconnected from the 12 V power supply. A lithium battery powers the clock and RAM when the primary 12 V DC is not connected. The lithium battery has an expected life of four years of continuous use. That is, the primary power source can be disconnected up to four years before the clock stops and data is lost.

The datalogger has 128 K bytes flash electrically erasable program memory (EEPROM) and 128 K bytes of static random access memory (SRAM). The flash EEPROM stores the operating system and the programs, SRAM is used for data and running the programs.

The installed device is a versatile datalogger suitable for a wide range of applications in science, industry and research. Typical applications are: environmental monitoring and control, structural monitoring, industrial testing, automatic weather stations and agricultural research.

The data acquisition system has switched outputs to power bridge-type sensors such as PRTs, strain gauges, load cells, pressure transducers and thermistors. The instruction set allows to control measures (analogue voltage, impulses), data processing (mathematical functions such as square root and polynomials up to fifth grade), data storage (max, min, average, standard deviation, total, etc.) and programming (programs can include conditional executions, loops and subroutines).

The data acquisition system operates from -20 °C to +70 °C, the inputs are fully protected against lightings and electric transient, so it can work in different environmental conditions. The channels are 8 differential, with a 4 digit resolution and ±0.1% accuracy.
## Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

### Structural Investigations

### Technical Characteristics (CEN –004-029)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of channels</td>
<td>8</td>
</tr>
<tr>
<td>Kind of memory</td>
<td>RAM with lithium battery</td>
</tr>
<tr>
<td>Kind of measure</td>
<td>Electricity 4-20 mA</td>
</tr>
<tr>
<td>Capacity</td>
<td>5117 1 channel readings; 2924 4 channel readings; 2274 6 channel readings</td>
</tr>
<tr>
<td>Conversion</td>
<td>12 bit</td>
</tr>
<tr>
<td>Format downloaded data</td>
<td>Compatible EXCEL (ASCII)</td>
</tr>
<tr>
<td>Precision</td>
<td>0.1%</td>
</tr>
<tr>
<td>Protection</td>
<td>IP66</td>
</tr>
<tr>
<td>Dimensions</td>
<td>265x130x75</td>
</tr>
<tr>
<td>Stability</td>
<td>100 ppm</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>From 0.1 sec (zero warm-up time) to 24h</td>
</tr>
<tr>
<td>Absorption</td>
<td>45 mA, 10 μA in stand by</td>
</tr>
<tr>
<td>Sensors warm-up time</td>
<td>From 0.1 to 25.4 sec</td>
</tr>
<tr>
<td>Voltage sensors</td>
<td>15 V dc</td>
</tr>
<tr>
<td>Communicator connector</td>
<td>9 poli DB9 type</td>
</tr>
<tr>
<td>Internal battery power</td>
<td>12 Vcc – 6 A/h with 8 alkaline batteries LR14 size C (½ torcia)</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-20/+60°C</td>
</tr>
<tr>
<td>Serial communication RS232</td>
<td>8 bit, 1 stop bit, 9600 baud</td>
</tr>
</tbody>
</table>
6.1.2. Displacement Transducer

Displacement transducers used have been designed to obtain the maximum performances with extremely compact dimensions. “Hybrid Track” technology is applied: it consists in a conductive plastic film with high resistivity rolled up on a high precision coil. Conductive plastic film slides through a high precision metallic contact. This technology grants an infinite resolution and a high durability. Temperature coefficient is extremely low, while the resistance remains practically stable at humidity variations.

Sensor is provided with spherical joints at the end that allow a precise positioning and a movement always directed along the axis of the instrument. At least, the sensor is protected form an aluminium container that conforms the protection grade IP66.

### TECHNICAL CHARACTERISTICS (CEN –004-029)

<table>
<thead>
<tr>
<th>Performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric stroke</td>
<td>25 mm</td>
</tr>
<tr>
<td>Resistance ±10%</td>
<td>1 kΩ</td>
</tr>
<tr>
<td>Independent linearity</td>
<td>Granted 0.25%</td>
</tr>
<tr>
<td></td>
<td>Typical 0.15%</td>
</tr>
<tr>
<td>Dissipation at 20°C</td>
<td>0.5 W</td>
</tr>
<tr>
<td>Maximum applicable voltage</td>
<td>25 V cc</td>
</tr>
<tr>
<td>Electric output</td>
<td>Min. 0.5% - Max 99.5% of applied tension</td>
</tr>
<tr>
<td>Resolution</td>
<td>Practically infinite</td>
</tr>
<tr>
<td>Repeatability</td>
<td>Minor of 0.01 mm</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-30 °C to +100 °C</td>
</tr>
<tr>
<td>Isolation</td>
<td>&gt; 100 MΩ at 500 V cc</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical stroke E</td>
<td>25 – 50 mm</td>
</tr>
<tr>
<td>Mechanical stroke M</td>
<td>29 – 54 mm</td>
</tr>
<tr>
<td>Body length</td>
<td>110.5 mm</td>
</tr>
<tr>
<td>Centres distance D</td>
<td>173.6 mm</td>
</tr>
<tr>
<td>Approx weight</td>
<td>109 g</td>
</tr>
<tr>
<td>Electrical connexion</td>
<td>3 wires with PVC sheath</td>
</tr>
</tbody>
</table>

![Diagram of Displacement Transducer](image)
6.1.3. **Thermal Sensor**

The temperature sensors used are thermistor type; the detection system is based on the measurement of the resistance express in $\Omega$ (Ohm) of a platinum wire (Pt100) whose value is a linear function of temperature.

### TECHNICAL CHARACTERISTICS

<table>
<thead>
<tr>
<th>Misure range</th>
<th>-50 ° + 80 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material probe</td>
<td>Anticorodal aluminium</td>
</tr>
<tr>
<td>Precision</td>
<td>± 0.1 °C</td>
</tr>
<tr>
<td>Sensibility</td>
<td>0.01 °C</td>
</tr>
<tr>
<td>Output signal</td>
<td>4-wire resistance</td>
</tr>
</tbody>
</table>

![Diagram of a thermal sensor](image)
6.1.4. **Multipolar Shielded Cables**

For the transmission of the signals from the instruments to the datalogger are used four and six-conductor cables, with sections $0.22 \div 0.5 \text{ mm}^2$. They have a shield made of red copper, with a covering more than 85%, to prevent electric interferences and a protection to external agents; they are also non-inflammable according to CEI 20-22 standards.
6.2. Location of the Instrumentation

KEY OF SYMBOL

- F-n° Displacement transducer
- T-n° Thermometer
- DAU - Data Acquisition Unit

NOTE: for each instrument, the label shows the height of installation with respect to the local pavement (h) and the total elevation (h tot) with respect to the ground floor level of the cathedral
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

VIA DELLA FONTE DI FAINO 2A • Tel +39-06-5746335 +39-06-5747860 Fax +39-06-5781288
OBJECT
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Fe-6

+39 06 574 6335
+39 06 574 7860
Fax +39 06 578 1288
6.3. **PHOTOGRAPHIC DOCUMENTATION**

*Photo 1 – Displacement transducer Fe-1*

*Photo 2 – Displacement transducer Fe-2*
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Photo 3 – Displacement transducer Fe-3

Photo 4 – Displacement transducer Fe-4
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

STRUCTURAL INVESTIGATIONS

Photo 5 – Displacement transducer Fe-5

Photo 6 – Displacement transducer Fe-6
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
STRUCTURAL INVESTIGATIONS

Photo 7 – External thermal sensor

Photo 8 – Data Acquisition Unit and internal thermal sensor
6.4. PLOT OF SAMPLED VALUES

In the following pages shows the time trend graphs of the measurements performed during the period between November 7, 2012 and September 2, 2013.

In the graph relative to the temperature sensors on ordinate (Y axe) are the absolute value of the measured temperature, while in the abscissa (X axe) is arranged the time, expressed in months and days.

Regarding the representation of the values relating the lesions opening transducers, we specify that the recorded values are first adjusted respect the zero measure (first acquisition, "offset")and, in this way, is possible to directly assess the trend of changes (relative measurements) regardless the initial absolute value.

The current collection interval is 6 hours (4 acquisitions per day) for all instruments installed.
6.4.1. Displacement transducers
MONITORING SYSTEM
Displacement trasducer Fe-2

Monitoring period: 07/11/2012 - 20/09/2013

Displacement (mm)
Opening

SVETITSKHOVELI CATHEDRAL
MTSKHETA

MONITORING SYSTEM
Displacement trasducer Fe-2

Monitoring period: 07/11/2012 - 20/09/2013

Displacement (mm)
Opening

SVETITSKHOVELI CATHEDRAL
MTSKHETA

MONITORING SYSTEM
Displacement trasducer Fe-2

Monitoring period: 07/11/2012 - 20/09/2013

Displacement (mm)
Opening
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

Monitoring System

Displacement Transducer Fe-3

Monitoring period: 07/11/2012 - 20/09/2013
SVETITSKOVELI CATHEDRAL
MTSKHETA
MONITORING SYSTEM
Displacement trasducer Fe-4

Monitoring period: 07/11/2012 - 20/09/2013
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MONITORING SYSTEM
Displacement transducer Fe-5

Monitoring period: 07/11/2012 - 20/09/2013

Displacement (mm)
Opening  Closing

Month: December -12  November -12  September -13  August -13  July -13  June -13  May -13  April -13  March -13  February -13  January -13

Graphical representation of displacement over time.
SVETITSKHOVELI CATHEDRAL
MTSKHETA
MONITORING SYSTEM
Displacement trasducer Fe-6

Monitoring period: 07/11/2012 - 20/09/2013

Displacement (mm)
6.4.2. Thermal sensors
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MONITORING SYSTEM
External thermal sensor T-ext

Monitoring period: 07/11/2012 - 20/09/2013

Temperature (°C)
7. ANALYSIS OF THE RESULTS

In order to acquire information about mechanical properties, deformability and strength of the masonry forming the Svetitskhoveli Cathedral in Mtskheta, Georgia, was performed a campaign of structural investigations.

The vertical structures (masonry and pillars) and the vault have been investigated by videoendoscopic survey inside Ø 25 mm holes having a maximum depth of 120 cm. Were also conducted microseismic-sonic tests in order to assess the masonry homogeneity and laboratory tests for the determination of mechanical characteristics of the elements that constitute the masonry (aggregates and binder).

The following table shows a summary of all the non-destructive investigations carried out on the structures and testing of materials taken in situ.

<table>
<thead>
<tr>
<th>INVESTIGATION ON THE STRUCTURE AND MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n. 46</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>n. 7</strong></td>
</tr>
<tr>
<td><strong>n. 1</strong></td>
</tr>
<tr>
<td><strong>n. 28</strong></td>
</tr>
</tbody>
</table>
7.1. VERTICAL STRUCTURES

The perimeter walls are constituted by an inner-core masonry in which blocks of sandstone are arranged on a regular basis to form two facings (exterior and interior), while the inner core is characterized by the presence of fragments of sandstone and pebbles limestone bounded with mortar of lime and sand. In the locations investigated the masonry is free of voids, cavities or internal fractures and in good state of conservation.

Figure below shows as an example the stratigraphy of the V-33 and some photoframes.
The videoendoscopic investigations V-14, V-15, V-7 (performed at 1 m from pavement level) and V-43 (performed at 6.5 m from pavement level) permit to locate the position of the original pillars that following the reconstruction of architect Arsukidze in the XI century have been incorporated in the current perimeter wall.

The following table shows the stratigraphy relating to videoendoscopic investigation V-15, executed on the north side of the perimeter wall at 1 m above the floor, and V-43, which runs on the south side of the perimeter wall at 6.5 m from pavement level.
Over the masonry investigated by videoendoscopy V-14 has been executed the sonic-microseismic test S-5 (refer to the attached color map). The high average speed of the waves through the masonry (\( V_m = 1049 \text{ m/s} \)) implies a compact masonry without cavities. The values measured by the sonic surveys S-3 and S-6, performed respectively on the south side of the perimeter wall and the north side, are modest and are characteristic of a inner-core masonry.

<table>
<thead>
<tr>
<th>Sonic Test</th>
<th>Element</th>
<th>( V_{\text{min}} )</th>
<th>( V_{\text{max}} )</th>
<th>( V_m )</th>
<th>( \sigma )</th>
<th>( \sigma/V_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>masonry</td>
<td>737</td>
<td>1353</td>
<td>1049</td>
<td>186</td>
<td>17.7</td>
</tr>
<tr>
<td>3</td>
<td>masonry</td>
<td>614</td>
<td>897</td>
<td>764</td>
<td>78</td>
<td>10.2</td>
</tr>
<tr>
<td>6</td>
<td>masonry</td>
<td>352</td>
<td>859</td>
<td>613</td>
<td>150</td>
<td>24.5</td>
</tr>
</tbody>
</table>

On the following page is shown a plan of the Cathedral, which displays the videoendoscopic investigations performed on the perimeter walls and a schematic representation of the type of masonry.
OBJECT: CATHEDRAL OF SVEITSKHOVELI - MTSKHETA

KEY OF SYMBOLS:

- V-1: Videoendoscopic investigations approximately 1 m from inner perimeter line
- V-15: Videoendoscopic investigations approximately 1.5 m from inner perimeter line
- V-27: Videoendoscopic investigations on the vault, approximately 1.5 m from inner perimeter line
- V-3: Ancient pillar discovered by videoendoscopic investigations
- V-6: Outer masonry in sandstone blocks
- V-7: Inner core constituted by fragments of sandstone, schistose, limestones, rusted and oxidized

VIDEOENDOSCOPIC INVESTIGATIONS RESULTS - PERIMETER WALLS

CATHEDRAL OF SVEITSKHOVELI - MTSKHETA

STUDIO PROGETTAZIONE E CONTROLLI - ROMA

SPC srl
The current pillars are the result of the reconstruction of the XI century when the original pillars, cross-shaped and made by inner-core masonry, were covered with a new masonry to increase the cross section of the vertical element, while four pillars have been eliminated.

The following figure shows a schematic representation of the pillar investigated by the V-18, V-19, V-23, V-24, represented in its original position, and the thickness of the sandstone blocks.
Hereinafter attached is a schematic reconstruction of the pillar investigated by videoendoscopy V-4, V-20, V-21, performed at 1 m from the pavement level, V-41 performed at approximately 6.30 m above the floor and V-39 performed at about 12.30 m from the pavement. From the diagram it is possible to estimate the thickness of the external face and the position of the inner-core.
The microseismic-sonic tests performed on the pillars show a high average speed implies a compact masonry without cavities.
Object: Cathedral of Svetitskhoveli - Mtskheta

Structural Investigations

Svetitskhoveli Cathedral

Videoendoscopic investigations results - pillars

Key of Symbols:
- V-n: Videoendoscopic investigations, approximately 7.5 m from pavement level
- V-s: Videoendoscopic investigations, approximately 4.5 m from pavement level
- V-f: Videoendoscopic investigations, approximately 1.5 m from pavement level
- V-c: Videoendoscopic investigations on the vault, approximately 7.5 m from pavement level
- Σ: painted pillar discovered by videoendoscopic investigations
- Β: outer surface in sandstone blocks
- Α: inner core constituted by fragments of sandstone, silt, tuff, limestone, tuff, surrounded with a layer of sand and lime
7.2. VAULT

The diagrams below show the results for the videoendoscopic tests executed on the vault. The videoendoscopy V-45 was performed on a vault 70 cm thick made by masonry blocks of limestone and sandstone bounded by mortar lime.

location of videoendoscopic investigation V-45

videoendoscopic investigation V-45 – stone vault

Depth 30 cm – stone blocks

Depth 50 cm – sandstone blocks
The vault investigated by the V-46 videoendoscopy is made of brick masonry and mortar lime and has a thickness of 40 cm.
7.3. MECHANICAL LABORATORY TESTS

The results of the conducted mechanical tests are reported in the following table.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Specimen</th>
<th>Type</th>
<th>R/C</th>
<th>Height [mm]</th>
<th>Base [mm]</th>
<th>Density dry [kg/m³]</th>
<th>Ultimate tension [MPa]</th>
<th>Elastic Modulus range [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>sandstone</td>
<td>R</td>
<td>59</td>
<td>58</td>
<td>58</td>
<td>2055</td>
<td>17,84</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td></td>
<td>R</td>
<td>56</td>
<td>59</td>
<td>56</td>
<td>2168</td>
<td>20,74</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td></td>
<td>R</td>
<td>41</td>
<td>40</td>
<td>40</td>
<td>2037</td>
<td>19,59</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td></td>
<td>R</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>2108</td>
<td>17,23</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td></td>
<td>R</td>
<td>41</td>
<td>40</td>
<td>41</td>
<td>2063</td>
<td>19,05</td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>brick</td>
<td>R</td>
<td>49</td>
<td>51</td>
<td>52</td>
<td>1739</td>
<td>8,58</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td></td>
<td>R</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>1742</td>
<td>6,57</td>
</tr>
</tbody>
</table>

*NOTE: sample 3-III: failure occurred along a pre-existing defect

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>sandstone</td>
<td>2037</td>
<td>2527</td>
<td>2269</td>
<td>2269</td>
<td>17,23</td>
<td>39,83</td>
<td>23,60</td>
<td>4,62</td>
<td>23,05</td>
<td>-</td>
</tr>
<tr>
<td>brick</td>
<td>1720</td>
<td>1875</td>
<td>1794</td>
<td>1794</td>
<td>6,57</td>
<td>22,71</td>
<td>16,60</td>
<td>2,38</td>
<td>17,50</td>
<td>11,80</td>
</tr>
<tr>
<td>black limestone</td>
<td>2640</td>
<td>2699</td>
<td>2659</td>
<td>2659</td>
<td>186,51</td>
<td>190,85</td>
<td>184,27</td>
<td>3,31</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ophicalcite</td>
<td>1631</td>
<td>1654</td>
<td>1643</td>
<td>1643</td>
<td>7,97</td>
<td>10,72</td>
<td>9,04</td>
<td>3,31</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>mortar</td>
<td>1712</td>
<td>1754</td>
<td>1734</td>
<td>1734</td>
<td>1,01</td>
<td>1,91</td>
<td>1,50</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*NOTE: The value 70,44 MPa relative to the specimen 3-III was not considered
7.4. MINERALOGICAL ANALYSIS OF THE MORTAR

From the mineralogical tests conducted on the sample of mortar, it was found that the mixture is a grey one obtained as a mix of common lime and mainly carbonatic and less silicatic fluvial sand; its state of preservation appears sufficiently good. The binder/aggregate ratio is evaluable to values close to 3.5/1.

Thin section, transmitted light, and 40 X, N+
7.5. MONITORING SYSTEM

The structural monitoring system, implemented by the installation of six displacement transducers and two temperature sensors, active from November 7, 2012 has the aim to provide for the control of the possible evolution over time of the monitored cracks located on the wall of the Cathedral.

The following tables show the analysis of the acquisitions, but it is useful to specify that during the mission in September 2013, the monitoring system was inactive due to a disconnection from the power supply system occurred at the end of February 2013. So, in the graphs below, there is a time period (March ÷ September 2013) where it is not possible to know with certainty the movement of the cracks.

The following tables summarize the measurements from November 7, 2012 and September 20, 2013: in these tables are shown the start values, end values, minimum and maximum measured, also calculated are the differences between the values at the beginning and the end of the period and the maximum excursion (the difference between the maximum and minimum values).

### SUMMARY TABLE OF VALUES MEASUERED BY DISPLACEMENT TRANSDUCERS

<table>
<thead>
<tr>
<th>Displacement transducers</th>
<th>Monitoring period: 07/11/2012 - 20/09/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starting value</td>
</tr>
<tr>
<td>Fe25-1</td>
<td>0,000</td>
</tr>
<tr>
<td>Fe25-2</td>
<td>0,000</td>
</tr>
<tr>
<td>Fe25-3</td>
<td>0,000</td>
</tr>
<tr>
<td>Fe25-4</td>
<td>0,000</td>
</tr>
<tr>
<td>Fe25-5</td>
<td>0,000</td>
</tr>
<tr>
<td>Fe25-6</td>
<td>0,000</td>
</tr>
</tbody>
</table>

### SUMMARY TABLE OF VALUES MEASUERED BY THERMAL SENSORS

<table>
<thead>
<tr>
<th>Thermal sensors</th>
<th>Monitoring period: 07/11/2012 - 20/09/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starting value</td>
</tr>
<tr>
<td>Text</td>
<td>19,2</td>
</tr>
<tr>
<td>Int</td>
<td>20,0</td>
</tr>
</tbody>
</table>
The detection of the external temperature sensor (T-ext), in the period in which records are available, shows the characteristic cyclic pattern related to the succession of the seasons. The values recorded, close to 15 °C in the first stage, gradually decrease to the minimum value of -2 °C recorded on December 27, 2012, and then increased with the end of the cold season. Due to the missing data in the summer, maximum temperature was recorded on September 19 and it was 25.7 °C.

The internal temperature detected by the sensor T-1, located close to the Data Acquisition Unit, shows a trend that closely follows the outside temperature one: compared to the first presents minor fluctuations, which determine a lower maximum excursion (about 11 °C).
Below, a comparison is made between the trends detected by displacement transducers, placed on the main cracks identified, having all vertical patterns, and the corresponding values of the thermal cycle. In this way, estimating the influence of the changes originated by thermal effect, it is possible to quantify the possible occurrence of evolutionary phenomena.

The following chart shows the measurements relating to transducers Fe-1, Fe-2, Fe-3 and the internal temperature sensor. T-int. Please note that, in order to appreciate the movements, it is proposed in the tables a reduced range of ±0.5 mm for the deformations.

The movement’s transducers acquisitions of the cracks are in accordance to the oscillations of the internal temperature in the Cathedral; there has been an opening movement of the cracks when the temperature decreased and a following closure movement. At the end of the monitoring period the residual deformation value was positive for the three cracks, indicating the presence of an accumulation of opening deformation, but it should be noted that these values are extremely low (+0065 mm for Fe-1, +0035 mm for Fe-2 and Fe-3).
The cracks monitored by instruments Fe-4, Fe-5, Fe-6, have the common feature of an opening movement during the period of decrease of the temperature and a following phase of closure that determines a value of residual deformation negative for the three cracks. The instrument Fe-6, which controls a crack located in the drum, recorded a closing equal to -0.032 mm, while the lesions controlled by the transducers Fe-4 and Fe-5 present a closing equal to -0.079 and -0.097 mm. Also in this case the maximum excursion is a low value (about 0.3 mm) and the residual deformation in less than 0.01 mm.

It is therefore confirmed that during the monitoring period November 2012 ÷ September 2013, the size of the periodic movements of the cracks analyzed is small, but it is deemed necessary to continue record the data to confirm the dependence of the movements on the temperature fluctuations and to exclude the presence of evolutionary phenomena.
SVETITSKHOVELI CATHEDRAL
MTSKHETA (GEORGIA)

SPC STUDIO PROGETTAZIONE E CONTROLLI
Roma · via della Fonte di Fauno, n° 2a
tel. 06.5746335-06.5747860; fax 06.5781268
mail@spc-engineering.it
www.spc-engineering.it

Project Engineers:
Prof. Eng. Giorgio Croci
Dott. Eng. Cristiano Russo

Collaborators:
Dott. Eng. Giulio Rossi
Geom. Tiziano Stella
Dott. Eng. Anania Pietro
Dott. Eng. Libbio Antonelli

MATHEMATICAL MODEL

REPORT

<table>
<thead>
<tr>
<th>Rev.</th>
<th>Date</th>
<th>Description</th>
<th>Written</th>
<th>Verified</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11/11/13</td>
<td>1° ISSUE</td>
<td>Rossi/Stella/Anania/Antonelli</td>
<td>C. Russo</td>
<td>G. Croci</td>
</tr>
</tbody>
</table>
INDEX

1. FOREWORD.......................................................................................................................... 2

2. DESCRIPTION OF THE STRUCTURE.................................................................................. 3
   2.1. GEOMETRICAL OVERVIEW OF THE STRUCTURE....................................................... 3
   2.2. MATERIALS AND CONSTRUCTION TECHNIQUES....................................................... 6

3. FINITE ELEMENTS MODELS.............................................................................................. 7
   3.1. DESCRIPTION OF THE MODELS.................................................................................... 7

4. MODELING OF MATERIAL PROPERTIES............................................................................ 12
   4.1. MODELING OF SEISMIC ACTION.................................................................................. 16

5. ANALYSIS RESULTS.......................................................................................................... 20
   5.1. STATIC ANALYSIS: DEAD LOAD CASE........................................................................ 20

6. LINEAR DYNAMIC ANALYSIS........................................................................................... 33

7. SEISMIC BEHAVIOR OF THE STRUCTURE....................................................................... 42
   7.1.1. TRANSVERSAL SEISMIC COMBO: 1*D + 1*E_Y + 0.3*E_X + 0.3*E_Z..................... 43
   7.1.2. LONGITUDINAL SEISMIC COMBO: 1*D + 1*E_X + 0.3*E_Y + 0.3*E_Z.................... 51
   7.1.3. VERTICAL SEISMIC COMBO: 1*D + 0.3*E_X + 0.3*E_Y + 1*E_Z.......................... 57

8. STRUCTURAL SAFETY.......................................................................................................... 61
   8.1. SELF WEIGHT LOAD...................................................................................................... 62
   8.2. SEISMIC LOAD ............................................................................................................ 62
   8.3. LOCAL MODEL FOR INNER PILLAR ............................................................................ 64

9. CONCLUSIONS..................................................................................................................... 66
   9.1. DRUM AND DOME OVALIZATION .............................................................................. 67
   9.2. INCREMENT COMPRESSIVE STRESS FOR SISMIC LOAD ....... ............................... 70
   9.3. LOCAL TRASVERSAL WALL MODEL........................................................................... 71
   9.4. ARCHES SUPPORTED DRUM AND DOME VERTICAL REBAR................................. 72
1. **FOREWORD**

This report describes the behaviour of Cathedral of Svetitskhoveli under self weight load and seismic load.

To determinate the earthquake condition was used “Seismic Hazard Feasibility Study for Mtskheta Historical Site” of the Institute of Earth Sciences of Ilia State University.

The history has shown that Cathedral was buildings in the 4th century during the Mirian III empire. The rehabilitation and reconstruction works were headed by Catholicos Patriarch Melchisedek I. By his order an architect Arsukis-dze, at the beginning of the 11th century, reconstructed an old basilica, into the cruciform construction.

As a result of devastating earthquake in Georgia at the end of 13th century the dome fell down, it was repaired by Giorgi the Splendid in the first half of the 14th century.

For the second time the dome was destroyed by the Tamerlane’s warriors at the end of the 14th century.

Alexander I restored the pires but had them made thicker to reinforce the construction, so that they lost their original beauty. Even today it’s clearly seen how much the piers of the 11th and 15th centuries differ from one another. In the 11th century the arches were higher, the piers more refined and beautiful. Out of three arches of the western arm, only two were left. So if the distance among the arches was originally equal, after the 11th century restoration the step of one of them twice exceeded that of another.

The detailed inspections of Cathedral of Svetitskhoveli have shown that there are some cracks, especially on the arches and the drum and a plumb line deviation of transversal wall, in particular near the support structure of dome.

The analyses of global and local model shows some critical zone of the structure in which there are elevate stress value, especially on the arches crown. Further seismic analysis shows important increase of stress on pillars and dangerous differential displacements of the base of drum.

For these reasons, with particular attention to necessity to guarantee the respect of the monument and of the principle of conservation, have been proposed strengthening works on local elements to ensure safety and stability and prevent critical situation on earthquake effects.
2. DESCRIPTION OF THE STRUCTURE

The Svetitskhoveli Cathedral is an Orthodox Cathedral of Mtskheta in Georgia. It’s a masonry structure built between 1010 and 1029 on the waste of a church dating V century. In the following paragraphs is provided a geometrical description of the structure, materials and construction techniques.

2.1. GEOMETRICAL OVERVIEW OF THE STRUCTURE

The structure was building with a rectangular map with three aisles where central naves larger than the laterals. In the central of Cathedral there is a massive drum that supported a dome. The roofing is an articulated system of single and double pitched roof.

Picture.1.- Svetitskhoveli Cathedral – North side
The Cathedral plan dimensions are 60 m length, 25 m width and 27 m height. The height of the dome is approximately 49 m.

Picture 2.- Svetitskhoveli Cathedral - plan

Picture 3.- Svetitskhoveli Cathedral – elevation – North side
The vertical structures are composite by central pillars and perimeter walls. Four pillars supported drum and dome.

The horizontal structures are composed by vaults and arches that are supported by pillars and walls. There are different kind of vaults, in particular cross, barrel and ribbed vaults. All the arches are rounded arch.

Picture 4.- Brick ribbed vault and stone barrel vault

Picture 5.- Ancient inner pillar and drum
2.2. MATERIALS AND CONSTRUCTION TECHNIQUES

Pillars and perimeter walls are constituted by inner core masonry; the outer masonry made of sandstone blocks and inner core constituted by fragments of sandstone, ophicalcite, limestone rocks, bounded with a mortar of sand and lime.

To establish the mechanical characteristics of the material’s structure were accomplished a series of investigation. The results of which are reported on the material and investigation relationship.
3. **FINITE ELEMENTS MODELS**

3.1. **DESCRIPTION OF THE MODELS**

A structural analysis implementing a Finite Elements Model was performed to evaluate the vulnerability assessment and risk. The software used to calculation is Midas GEN. The model implemented is a linear elastic model where the geometric characteristic of the fabric is supposed made from a continuous elastic material. The geometric representation made with 3D and 2D finite element will reproduce carefully all the various structural members. In order to study the presence in the monument of structures made of facings/linings and inner part (made of large quantity of mortar with bricks and pebbles), in addition to the global model of the Cathedral, also some sub-model better describe the local behaviour in the principal critical portion.

![Picture 6. Masonry interior view – archaeological excavations](image)

In particular a local model of inner core masonry pillar aim to study the different distribution of stresses in the structures made of materials with different elastic modulus. The following pictures show the geometry of the global finite element model implemented in the Midas. In the model, the structure is restrained at the base with perfectly fixed nodes that do not allow any translations (along X, Y or Z axes).
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
MATHEMATICAL MODEL

Picture 7.- Model’s view from south-west (left side) and north-west (right side)

Picture 8.- Model’s view, longitudinal section from north side
**Object:**

**Cathedral of Svetitskhoveli - Mtskheta**

**Mathematical Model**

**Picture 9.** Model’s view, transversal section from west side

**Picture 10.** Modeling of main pillars, drum and dome; isometric view and section
The geometrical description of many vaults of the model was executed using 2D plate element. In the next picture is showed the model of vaults of the structure, in particular the vaults made of bricks (with estimated thickness of 40 cm) are indicated with red colour while the vaults made of square stone blocks (with estimated thickness of 60 cm) are indicated with blue colour. More about the use of 2D plate elements in the model, the masonry structure of the roof was executed considering a thickness of 30 cm with the appyling of a load to consider the presence of the granite slabs on the roof.
In the next is also showed the local-model of one of the main pillars of the structure executed to study the distribution of stresses in the structural elements considering the presence of two material in the section, the external and the internal one.
4. MODELING OF MATERIAL PROPERTIES

The material properties implemented in the model come from the results of the extensive investigations performed in the preliminary phase to achieve a significant knowledge of the building. The results of video-endoscopic investigations and compressive strength tests, in addition to the knowledge of reference values of mechanical properties for different kind of masonry (provided by Italian Codes) permitted to evaluate the parameters showed in the next table.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Specimen Type</th>
<th>Type</th>
<th>R/C</th>
<th>Height [mm]</th>
<th>Base [mm]</th>
<th>Density [kg/m³]</th>
<th>Ultimate tension [MPa]</th>
<th>Elastic Modulus [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I</td>
<td>sandstone</td>
<td>R</td>
<td>59</td>
<td>58</td>
<td>2055</td>
<td>17.84</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>sandstone</td>
<td>R</td>
<td>56</td>
<td>59</td>
<td>2070</td>
<td>34.54</td>
<td>0.54, 4.71, 4.62</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>sandstone</td>
<td>R</td>
<td>41</td>
<td>40</td>
<td>2037</td>
<td>19.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>sandstone</td>
<td>R</td>
<td>49</td>
<td>49</td>
<td>2108</td>
<td>17.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>sandstone</td>
<td>R</td>
<td>41</td>
<td>40</td>
<td>2063</td>
<td>19.05</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>I</td>
<td>brick</td>
<td>R</td>
<td>49</td>
<td>51</td>
<td>1739</td>
<td>8.58</td>
<td>0.20, 2.13, 2.38</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>brick</td>
<td>R</td>
<td>49</td>
<td>49</td>
<td>1742</td>
<td>6.57</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I</td>
<td>black limestone</td>
<td>R</td>
<td>52</td>
<td>51</td>
<td>2654</td>
<td>186.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>black limestone</td>
<td>R</td>
<td>52</td>
<td>51</td>
<td>2640</td>
<td>186.51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>black limestone</td>
<td>R</td>
<td>50</td>
<td>51</td>
<td>2643</td>
<td>70.44 *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>black limestone</td>
<td>R</td>
<td>39</td>
<td>39</td>
<td>2699</td>
<td>199.27</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>I</td>
<td>sandstone</td>
<td>R</td>
<td>50</td>
<td>52</td>
<td>2465</td>
<td>63.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>sandstone</td>
<td>R</td>
<td>51</td>
<td>50</td>
<td>2527</td>
<td>1.72, 16.60, 23.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>sandstone</td>
<td>R</td>
<td>44</td>
<td>42</td>
<td>2371</td>
<td>38.54</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>sandstone</td>
<td>R</td>
<td>43</td>
<td>43</td>
<td>2469</td>
<td>38.47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>sandstone</td>
<td>R</td>
<td>44</td>
<td>43</td>
<td>2525</td>
<td>64.85</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>I</td>
<td>brick</td>
<td>R</td>
<td>47</td>
<td>49</td>
<td>1860</td>
<td>26.69</td>
<td>1.02, 10.03, 17.50</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>brick</td>
<td>R</td>
<td>46</td>
<td>49</td>
<td>1785</td>
<td>30.45</td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>I</td>
<td>brick</td>
<td>R</td>
<td>40</td>
<td>41</td>
<td>1875</td>
<td>25.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>brick</td>
<td>R</td>
<td>39</td>
<td>40</td>
<td>1720</td>
<td>13.62</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>I</td>
<td>brick</td>
<td>R</td>
<td>40</td>
<td>39</td>
<td>1836</td>
<td>34.44</td>
<td>1.09, 10.60, 11.80</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>brick</td>
<td>R</td>
<td>37</td>
<td>39</td>
<td>1792</td>
<td>36.03</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>I</td>
<td>ophicalcite</td>
<td>R</td>
<td>44</td>
<td>45</td>
<td>1654</td>
<td>10.72</td>
<td>0.25, 2.00, 3.31</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>ophicalcite</td>
<td>R</td>
<td>34</td>
<td>35</td>
<td>1631</td>
<td>7.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>ophicalcite</td>
<td>R</td>
<td>31</td>
<td>31</td>
<td>1645</td>
<td>8.41</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>I</td>
<td>mortar</td>
<td>R</td>
<td>33</td>
<td>34</td>
<td>1754</td>
<td>1.91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>mortar</td>
<td>R</td>
<td>27</td>
<td>30</td>
<td>1738</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>mortar</td>
<td>R</td>
<td>19</td>
<td>21</td>
<td>1712</td>
<td>1.01</td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: sample 3-III: rupture occurred along a pre-existing defect*
Picture.15.: Video endoscopic investigation results
In the following table are reported mechanical characteristics of masonry types of the structure taken by the Italian code.

<table>
<thead>
<tr>
<th>Type of masonry</th>
<th>$f_c$ (N/cm²)</th>
<th>$f_m$ (N/cm²)</th>
<th>$E$ (N/mm²)</th>
<th>$G$ (N/mm²)</th>
<th>$w$ (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry stone</td>
<td>100 min-180 max</td>
<td>2.0 min-3.2 max</td>
<td>600 min-1050 max</td>
<td>230 min-350 max</td>
<td></td>
</tr>
<tr>
<td>Ashlar masonry blanks, with face of limited thickness and inner core</td>
<td>200 min-300 max</td>
<td>3.5 min-5.1 max</td>
<td>1020 min-1440 max</td>
<td>340 min-480 max</td>
<td></td>
</tr>
<tr>
<td>Masonry split stones with good texture</td>
<td>260 min-380 max</td>
<td>5.6 min-7.4 max</td>
<td>1500 min-1980 max</td>
<td>500 min-660 max</td>
<td></td>
</tr>
<tr>
<td>Masonry of soft stone (tafo, calcarenite, etc.)</td>
<td>140 min-240 max</td>
<td>2.8 min-4.2 max</td>
<td>900 min-1260 max</td>
<td>300 min-420 max</td>
<td></td>
</tr>
<tr>
<td>Masonry stone blocks squared</td>
<td>600 min-800 max</td>
<td>9.0 min-12.0 max</td>
<td>2400 min-3200 max</td>
<td>780 min-940 max</td>
<td></td>
</tr>
<tr>
<td>Masonry blocks and lime mortar</td>
<td>240 min-400 max</td>
<td>6.0 min-9.2 max</td>
<td>1200 min-1800 max</td>
<td>400 min-600 max</td>
<td></td>
</tr>
<tr>
<td>Masonry in mortar with lime cement (ce spessore UNI forniture c. 40%)</td>
<td>500 min-800 max</td>
<td>24 min-32 max</td>
<td>3400 min-5600 max</td>
<td>875 min-1300 max</td>
<td></td>
</tr>
<tr>
<td>Masonry in blocks laterizi semipeni (perc. fornitura c. 45%)</td>
<td>400 min-600 max</td>
<td>30.0 min-40.0 max</td>
<td>3600 min-5400 max</td>
<td>1080 min-1630 max</td>
<td></td>
</tr>
<tr>
<td>Masonry in blocks laterizi semipeni, with various thicknesses (perc. fornitura c. 45%)</td>
<td>300 min-400 max</td>
<td>10.0 min-13.0 max</td>
<td>2700 min-3600 max</td>
<td>810 min-1080 max</td>
<td></td>
</tr>
<tr>
<td>Masonry in blocks of calcarenite or argilla organica (perc. fornitura tra 45% e 65%)</td>
<td>150 min-200 max</td>
<td>9.5 min-12.5 max</td>
<td>1200 min-1600 max</td>
<td>300 min-400 max</td>
<td></td>
</tr>
<tr>
<td>Masonry in blocks of calcarenite semipeni (foriture &lt; 45%)</td>
<td>300 min-440 max</td>
<td>18.0 min-24.0 max</td>
<td>2400 min-3520 max</td>
<td>600 min-800 max</td>
<td></td>
</tr>
</tbody>
</table>

From the investigations executed on masonry elements, the investigation team has noted the good performance of mortar. For this reason in the calculation model we have taken into account a amplifying coefficient for resistance of masonry. In the following tables is reported the value of amplifying coefficient used in calculation model from the Italian code.
Considering the complexity of the structure and consequently the impossibility to consider in the global model the presence of external lining and inner part, an equivalent material was implemented for vertical walls.

The mechanical characteristics of vertical walls material used in calculation models are average values taken from picture 16 (Tables of Italian code) amplified as written above using the tables on picture 17.

In the following table are reported the mechanical characteristics of equivalent materials in the calculation models.

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Elastic Modulus E (MPa)</th>
<th>Compressive Strength (MPa)</th>
<th>Specific Weight (kN/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry of Vertical Structures</td>
<td>1700</td>
<td>3.5</td>
<td>20</td>
</tr>
<tr>
<td>Horizontal Structures-Made of Bricks</td>
<td>2250</td>
<td>4.8</td>
<td>18</td>
</tr>
<tr>
<td>Horizontal Structures-Made of Square Stones</td>
<td>3360</td>
<td>8.4</td>
<td>22</td>
</tr>
</tbody>
</table>

Picture.18.- Masonry properties implemented in the finite elements model
4.1. MODELING OF SEISMIC ACTION

The seismic action implemented was defined starting from the “Seismic Hazard Feasibility Study for Mtskheta Historical Site” of the Institute of Earth Sciences of Ilia State University and “Minister of Economic Development of Georgia 7 October, 2009 Tbilisi – On approval of design/construction standards and regulations_antiseismic constructions”.

The study shows that the site’s area of Mtskheta is located in the Intensity 8 zone of the Acting Seismic Hazard Assessment Map adopted in 2009 and included in National Seismic Codes. The PGA (Peak Ground Acceleration) values are in the range 0,16 - 0,18g, as shows in the following figure.

![Seismic map for structure site](image-url)
In the absence of the response spectrum of site so it was chosen to use the response spectrum calculate with EN 1998.

The seismic PGA is evaluate on a useful life of 50 year with 2% of probability of overcoming.

Without any dynamic information on foundation soil, it was chosen to use a design spectrum with type of soil 1-C. The choice of the type 1 is due to assess a safe seismic action while the C category of soil is a medium stiffness. The difference between the C category and E category (maxim amplification of horizontal acceleration) is about 20% of horizontal acceleration then the design seismic action have a conservative value.

In the next imagine shows the horizontal elastic spectrum used for the analyses.

![Horizontal elastic spectrum](attachment:image.png)

It is also used a vertical elastic spectrum to assess the sussultatory component of seismic shows below.
The analyses of the acceleration due to the seismic is cutting on 2 seconds because the maximum vibration period is about 0.6 seconds.
For horizontal component was chosen a structure factor $q$ equal to 2. A Research conducted by “Protezione Civile” and same of most important Italian university (including “La Sapienza di Roma”) shows an interesting graphic that offers the trend of percentage of conservative case in relationship at structure factor.
With a $q = 2$, the percentage of conservative case is equal at 99%. For this reason was chosen of modelling the seismic action with a structure factor equal to 2.

In the next figure is shows the design response spectrum used in the analyses.
5. **ANALYSIS RESULTS**

5.1. **STATIC ANALYSIS: DEAD LOAD CASE**

Static analysis is carried out considering only dead loads (self-weights). Structural deformations and stresses are highlighted using a chromatic scale with each single color representing a range of values. Positive values are used for deformations, negative values for compression stresses and positive values for tensile stresses.

With reference to the values indicated in the next pictures it can be notices as the main displacements are located in the dome and in the central area of the structure. The high weight of the dome cause the deformation of the central arches, pillars and external walls, primarily in transversal direction (X direction). The considerable out of plumbs observed in the central pillars is related to the not countered thrust of arches particularly in transversal direction. Naturally the real displacements measured in the structure are larger than those provided by the model, because of the constitutive law implemented is linear elastic, where reduction of elastic modulus due to damaging is not considered. Besides the displacements and the out of plumbs of structure are also probably related to the cumulative damages due to past seismic events and prolonged action of static loads.

![Deformed shape, isometric view](image)
Object:

CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MATHEMATICAL MODEL

Picture 21.- Deformed shape, top view

Picture 22.- Deformed shape of global structure (view from East side) and central pillars
In the next pictures the displacements of the two couples of main pillars (west and east side) with their adjacent transversal walls. The high thrusts of arch over the pillars due to the heavy dome cause the horizontal displacement of main pillars and of the adjacent lateral walls that must contrast the above mentioned thrusts.

The maximum horizontal displacement of lateral walls is localized at the level of lateral arches, where the reduction of section towards the upper portion of walls is related to an important reduction of stiffness.

It’s interesting to observe that the shape of out of plumbs of survey in one of the two facade walls is very similar to that provided by the analysis.

Picture.23.- Deformed shape of main pillars and transversal walls, alignment east side
Picture 24: Maximum tensile stresses of main pillars and transversal walls, alignment east side
In the next pictures the damages localized in the lateral wall near to the south facade and probably due to .

Picture 25.- Deformed shape of main pillars and transversal walls, alignment west side

Picture 26.- Damages localized in the lateral wall near to the south facade
The next picture shows the damage in one of the arches due to effects of static load. The perimetric wall deforms out, as shown in the below figure, causing a loss of thrust on the arch. Deformation of the wall produce damage on the arch and on overlying wall. This phenomenon is visible on mathematical model by a concentration of tensile stress on arches.

Picture 27. - Maximum tensile stresses of main pillars and transversal walls, alignment west side
In the following picture shows the state of stresses in the dome. The main stress on base of structure is interested by values of tensile and shear stresses. Those high values are related to the large deformations of the main arches located under the heavy dome.

Picture 28. - Maximums tensile stresses of the dome, view from the bottom

Picture 29. - Maximums shear stresses of the dome, view from the bottom
The photos show that many cracks are located at the base of dome and in the drum, in agreement to the state stresses previously shown.

Picture.31.- Cracks in the drum area
The stresses $\sigma_{ZZ}$ of model are showed in the following picture.

![Hight stressed vertical elements](image)

**Picture.32.- Vertical stress ZZ, view from the bottom**
Verily the peak of stress is reached in the external portion of the pillars where is located the external lining realized by square stone of sandstone.

<table>
<thead>
<tr>
<th></th>
<th>F&lt;sub&gt;Z&lt;/sub&gt;</th>
<th>F&lt;sub&gt;X&lt;/sub&gt;</th>
<th>F&lt;sub&gt;Y&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>PILLAR N –E</td>
<td>3896 kN</td>
<td>119 kN</td>
<td>-79 kN</td>
</tr>
<tr>
<td>PILLAR N –O</td>
<td>4902 kN</td>
<td>-254 kN</td>
<td>-243 kN</td>
</tr>
<tr>
<td>PILLAR S –E</td>
<td>3874 kN</td>
<td>117 kN</td>
<td>80 kN</td>
</tr>
<tr>
<td>PILLAR S –O</td>
<td>4905 kN</td>
<td>-250 kN</td>
<td>240 kN</td>
</tr>
</tbody>
</table>

Picture 33.- Vertical stress ZZ of central pillars

Picture 34.- Table of resultant reactions at the base of main pillars
In order to study the distribution of stresses in the structural elements considering the presence of the two materials in the section of the main pillars (and in the other vertical structural elements), a sub model was implemented. In the next table the material properties considered for the external lining and the internal part are showed. Those value were chosen starting to the results of compressive strength tests (see Paragraph “Modeling of material properties”).

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic Modulus E (MPa)</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTERNAL LINING OF PILLARS</td>
<td>2500</td>
<td>17*</td>
</tr>
<tr>
<td>INNER PART OF PILLARS</td>
<td>900</td>
<td>1**</td>
</tr>
</tbody>
</table>

* value referred to the lower value obtained from compressive strength test for sandstone

** value referred to the lower value obtained from compressive strength test mortar

The following pictures show the different distribution of the vertical stresses $\sigma_{zz}$ considering the two materials and the homogeneous section. The analysis were carried out applying to the model of pillar only a vertical gravity load. In the first case in the external portion of pillar the stresses $\sigma_{zz}$ reach values between 1,5 – 2 MPa, while in the inner part the stresses are of about 1 MPa. Differently in the second model the stresses are higher in the external portion (more stiff), with values between 2 – 2,7 MPa and lower in the internal one (values between 0,67 – 1 Mpa).

Hence the sub model shows for the external lining of pillar values of stresses higher of about the 30% in the external portion (2,35 MPa against 1,75 MPa) towards the model with homogeneous material. Considering the high values of strength obtained by tests of the sandstone, the check on compressive strength is verified.

\[17 \text{ MPa} / 3 \approx 5,7 \text{ MPa} > 2,35 \approx 3 \text{ MPa}\]
However with reference to the inner side of pillar the check is not satisfied because of the low value of resistance obtained from the tests.

\[ 1 \text{ MPa} / 3 = 0.33 \text{ MPa} < 0.83 \approx 1.1 \text{ MPa} \]

Picture 36. - Results of sub model of the pillar: stress SZZ in the section with homogeneous material (figure in the top) and in the section with external lining and inner part (figure below)
In conclusion also considering the presence of the two materials in the section of pillars, the checks on compression are not completely satisfied.

Finally the maximum tensile stresses in the main arches are showed in the next. As previously described, the presence of the heavy dome cause the high thrusts and the deformation of arches and consequently the reaching of high tensile stresses in the arch keys.

Picture.37.- Maximum tensile stresses in the main arches
6. LINEAR DYNAMIC ANALYSIS

In the modal analyses was investigate 91% of X masses, 92% of Y masses and 80% of vertical masses.

The modal analyses shows a first vibration period of 0.54 s witch moves 64% of seismic mass in transversal direction (Y direction) of the structure. The vibration mode 2, 4 and 5 moves the longitudinal masses (X direction) with periods included 0.39 s and 0.29 s. To correctly evaluate the seismic stress on the structure is necessary apply a complete quadratic combination (CQC).

There is a modal coupling between 4 and 5 mode of vibration.

The mode 7 have a participation mass in X and Y direction producing a little torsion effect due to dissymmetry of the structure.

The mode 13 and 14 represent a part of vertical masses (Z direction). The remaining masses is distributed in the subsequent modes of the structure. To reaching a good participation mass it was necessary calculate 100 modes of vibration of the structure.

In following tables are reported the vibration periods and participation mass for each mode.
**Object:**

CATHEDRAL OF SVETITSKHOVELI - MTSKHE

**Mathematical model**

<table>
<thead>
<tr>
<th>Mode No</th>
<th>Frequency (rad/sec)</th>
<th>Period (cycle/sec)</th>
<th>Period (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.6456</td>
<td>1.8535</td>
<td>0.5395</td>
</tr>
<tr>
<td>2</td>
<td>16.0775</td>
<td>2.5588</td>
<td>0.3908</td>
</tr>
<tr>
<td>3</td>
<td>18.6702</td>
<td>2.9715</td>
<td>0.3365</td>
</tr>
<tr>
<td>4</td>
<td>21.0974</td>
<td>3.3578</td>
<td>0.2978</td>
</tr>
<tr>
<td>5</td>
<td>21.1154</td>
<td>3.3606</td>
<td>0.2976</td>
</tr>
<tr>
<td>6</td>
<td>22.5872</td>
<td>3.5949</td>
<td>0.2782</td>
</tr>
<tr>
<td>7</td>
<td>30.3198</td>
<td>4.8256</td>
<td>0.2072</td>
</tr>
<tr>
<td>8</td>
<td>30.6469</td>
<td>4.8776</td>
<td>0.205</td>
</tr>
<tr>
<td>9</td>
<td>32.1971</td>
<td>5.1243</td>
<td>0.1951</td>
</tr>
<tr>
<td>10</td>
<td>32.9989</td>
<td>5.2519</td>
<td>0.1904</td>
</tr>
<tr>
<td>11</td>
<td>36.3783</td>
<td>5.7898</td>
<td>0.1727</td>
</tr>
<tr>
<td>12</td>
<td>37.9264</td>
<td>6.0362</td>
<td>0.1657</td>
</tr>
<tr>
<td>13</td>
<td>38.7114</td>
<td>6.1611</td>
<td>0.1623</td>
</tr>
<tr>
<td>14</td>
<td>39.9213</td>
<td>6.3537</td>
<td>0.1574</td>
</tr>
<tr>
<td>15</td>
<td>42.3007</td>
<td>6.7324</td>
<td>0.1485</td>
</tr>
<tr>
<td>16</td>
<td>42.9841</td>
<td>6.8411</td>
<td>0.1462</td>
</tr>
<tr>
<td>17</td>
<td>43.6364</td>
<td>6.9449</td>
<td>0.144</td>
</tr>
<tr>
<td>18</td>
<td>43.8125</td>
<td>6.973</td>
<td>0.1434</td>
</tr>
<tr>
<td>19</td>
<td>46.1523</td>
<td>7.3454</td>
<td>0.1361</td>
</tr>
<tr>
<td>20</td>
<td>46.7901</td>
<td>7.4469</td>
<td>0.1343</td>
</tr>
<tr>
<td>21</td>
<td>48.4158</td>
<td>7.7056</td>
<td>0.1298</td>
</tr>
<tr>
<td>22</td>
<td>48.6575</td>
<td>7.7441</td>
<td>0.1291</td>
</tr>
<tr>
<td>23</td>
<td>48.9955</td>
<td>7.7979</td>
<td>0.1282</td>
</tr>
<tr>
<td>24</td>
<td>50.4798</td>
<td>8.0341</td>
<td>0.1243</td>
</tr>
<tr>
<td>25</td>
<td>51.1411</td>
<td>8.1394</td>
<td>0.1229</td>
</tr>
<tr>
<td>26</td>
<td>51.2248</td>
<td>8.1527</td>
<td>0.1227</td>
</tr>
<tr>
<td>27</td>
<td>52.7359</td>
<td>8.3932</td>
<td>0.1191</td>
</tr>
<tr>
<td>28</td>
<td>53.3215</td>
<td>8.4864</td>
<td>0.1178</td>
</tr>
<tr>
<td>29</td>
<td>53.716</td>
<td>8.5492</td>
<td>0.117</td>
</tr>
<tr>
<td>30</td>
<td>54.0233</td>
<td>8.5981</td>
<td>0.1163</td>
</tr>
<tr>
<td>31</td>
<td>55.3227</td>
<td>8.8049</td>
<td>0.1136</td>
</tr>
<tr>
<td>32</td>
<td>55.7842</td>
<td>8.8783</td>
<td>0.1126</td>
</tr>
<tr>
<td>33</td>
<td>56.8551</td>
<td>9.0488</td>
<td>0.1105</td>
</tr>
<tr>
<td>34</td>
<td>57.9528</td>
<td>9.2235</td>
<td>0.1084</td>
</tr>
<tr>
<td>35</td>
<td>58.1004</td>
<td>9.247</td>
<td>0.1081</td>
</tr>
<tr>
<td>36</td>
<td>58.7148</td>
<td>9.3448</td>
<td>0.107</td>
</tr>
<tr>
<td>37</td>
<td>59.2124</td>
<td>9.424</td>
<td>0.1061</td>
</tr>
<tr>
<td>38</td>
<td>59.8238</td>
<td>9.5213</td>
<td>0.105</td>
</tr>
<tr>
<td>39</td>
<td>60.495</td>
<td>9.6281</td>
<td>0.1039</td>
</tr>
<tr>
<td>40</td>
<td>62.8726</td>
<td>10.0065</td>
<td>0.0999</td>
</tr>
<tr>
<td>41</td>
<td>62.9458</td>
<td>10.0181</td>
<td>0.0998</td>
</tr>
<tr>
<td>42</td>
<td>63.7327</td>
<td>10.1434</td>
<td>0.0986</td>
</tr>
<tr>
<td>43</td>
<td>63.8089</td>
<td>10.1555</td>
<td>0.0985</td>
</tr>
<tr>
<td>44</td>
<td>64.0956</td>
<td>10.2011</td>
<td>0.098</td>
</tr>
<tr>
<td>45</td>
<td>64.8534</td>
<td>10.3217</td>
<td>0.0969</td>
</tr>
<tr>
<td>46</td>
<td>65.5529</td>
<td>10.4331</td>
<td>0.0958</td>
</tr>
<tr>
<td>47</td>
<td>66.8303</td>
<td>10.6364</td>
<td>0.094</td>
</tr>
<tr>
<td>48</td>
<td>67.475</td>
<td>10.739</td>
<td>0.0931</td>
</tr>
<tr>
<td>49</td>
<td>67.8555</td>
<td>10.7995</td>
<td>0.0926</td>
</tr>
</tbody>
</table>
## Mathematical Model - Cathedral of Svetitskhoveli - Mtskheta

<table>
<thead>
<tr>
<th>Mode No</th>
<th>Frequency (rad/sec)</th>
<th>Period (cycle/sec)</th>
<th>Period (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>68.8279</td>
<td>10.9543</td>
<td>0.0913</td>
</tr>
<tr>
<td>51</td>
<td>69.6255</td>
<td>11.0812</td>
<td>0.0902</td>
</tr>
<tr>
<td>52</td>
<td>70.4624</td>
<td>11.2144</td>
<td>0.0892</td>
</tr>
<tr>
<td>53</td>
<td>72.1597</td>
<td>11.4846</td>
<td>0.0871</td>
</tr>
<tr>
<td>54</td>
<td>72.965</td>
<td>11.6127</td>
<td>0.0861</td>
</tr>
<tr>
<td>55</td>
<td>73.9503</td>
<td>11.7696</td>
<td>0.085</td>
</tr>
<tr>
<td>56</td>
<td>74.3612</td>
<td>11.835</td>
<td>0.0845</td>
</tr>
<tr>
<td>57</td>
<td>74.7086</td>
<td>11.8902</td>
<td>0.0841</td>
</tr>
<tr>
<td>58</td>
<td>75.6216</td>
<td>12.0356</td>
<td>0.0831</td>
</tr>
<tr>
<td>59</td>
<td>76.4751</td>
<td>12.1714</td>
<td>0.0822</td>
</tr>
<tr>
<td>60</td>
<td>76.9024</td>
<td>12.2394</td>
<td>0.0817</td>
</tr>
<tr>
<td>61</td>
<td>77.2377</td>
<td>12.2928</td>
<td>0.0813</td>
</tr>
<tr>
<td>62</td>
<td>77.6677</td>
<td>12.3612</td>
<td>0.0809</td>
</tr>
<tr>
<td>63</td>
<td>77.7986</td>
<td>12.382</td>
<td>0.0808</td>
</tr>
<tr>
<td>64</td>
<td>78.3745</td>
<td>12.4737</td>
<td>0.0802</td>
</tr>
<tr>
<td>65</td>
<td>79.1656</td>
<td>12.5996</td>
<td>0.0794</td>
</tr>
<tr>
<td>66</td>
<td>79.9182</td>
<td>12.7194</td>
<td>0.0786</td>
</tr>
<tr>
<td>67</td>
<td>80.6609</td>
<td>12.8376</td>
<td>0.0779</td>
</tr>
<tr>
<td>68</td>
<td>81.2588</td>
<td>12.9327</td>
<td>0.0773</td>
</tr>
<tr>
<td>69</td>
<td>81.8442</td>
<td>13.0259</td>
<td>0.0768</td>
</tr>
<tr>
<td>70</td>
<td>82.0684</td>
<td>13.0616</td>
<td>0.0766</td>
</tr>
<tr>
<td>71</td>
<td>82.5406</td>
<td>13.1367</td>
<td>0.0761</td>
</tr>
<tr>
<td>72</td>
<td>83.2522</td>
<td>13.25</td>
<td>0.0755</td>
</tr>
<tr>
<td>73</td>
<td>83.5665</td>
<td>13.3</td>
<td>0.0752</td>
</tr>
<tr>
<td>74</td>
<td>83.7843</td>
<td>13.3347</td>
<td>0.075</td>
</tr>
<tr>
<td>75</td>
<td>84.1672</td>
<td>13.3956</td>
<td>0.0747</td>
</tr>
<tr>
<td>76</td>
<td>84.5205</td>
<td>13.4518</td>
<td>0.0743</td>
</tr>
<tr>
<td>77</td>
<td>84.9998</td>
<td>13.5281</td>
<td>0.0739</td>
</tr>
<tr>
<td>78</td>
<td>85.1522</td>
<td>13.5524</td>
<td>0.0738</td>
</tr>
<tr>
<td>79</td>
<td>85.5014</td>
<td>13.608</td>
<td>0.0735</td>
</tr>
<tr>
<td>80</td>
<td>86.4539</td>
<td>13.7596</td>
<td>0.0727</td>
</tr>
<tr>
<td>81</td>
<td>87.0436</td>
<td>13.8534</td>
<td>0.0722</td>
</tr>
<tr>
<td>82</td>
<td>88.0296</td>
<td>14.0103</td>
<td>0.0714</td>
</tr>
<tr>
<td>83</td>
<td>88.7606</td>
<td>14.1267</td>
<td>0.0708</td>
</tr>
<tr>
<td>84</td>
<td>89.6941</td>
<td>14.2753</td>
<td>0.0701</td>
</tr>
<tr>
<td>85</td>
<td>89.8934</td>
<td>14.307</td>
<td>0.0699</td>
</tr>
<tr>
<td>86</td>
<td>90.8523</td>
<td>14.4596</td>
<td>0.0692</td>
</tr>
<tr>
<td>87</td>
<td>91.533</td>
<td>14.5679</td>
<td>0.0686</td>
</tr>
<tr>
<td>88</td>
<td>92.0244</td>
<td>14.6461</td>
<td>0.0683</td>
</tr>
<tr>
<td>89</td>
<td>92.4541</td>
<td>14.7145</td>
<td>0.068</td>
</tr>
<tr>
<td>90</td>
<td>93.3604</td>
<td>14.8588</td>
<td>0.0673</td>
</tr>
<tr>
<td>91</td>
<td>93.4124</td>
<td>14.867</td>
<td>0.0673</td>
</tr>
<tr>
<td>92</td>
<td>93.9218</td>
<td>14.9481</td>
<td>0.0669</td>
</tr>
<tr>
<td>93</td>
<td>94.0219</td>
<td>14.964</td>
<td>0.0668</td>
</tr>
<tr>
<td>94</td>
<td>94.7546</td>
<td>15.0807</td>
<td>0.0663</td>
</tr>
<tr>
<td>95</td>
<td>95.0469</td>
<td>15.1272</td>
<td>0.0661</td>
</tr>
<tr>
<td>96</td>
<td>95.7306</td>
<td>15.236</td>
<td>0.0656</td>
</tr>
<tr>
<td>97</td>
<td>96.2722</td>
<td>15.3222</td>
<td>0.0653</td>
</tr>
<tr>
<td>98</td>
<td>96.6704</td>
<td>15.3856</td>
<td>0.065</td>
</tr>
<tr>
<td>99</td>
<td>96.9204</td>
<td>15.4254</td>
<td>0.0648</td>
</tr>
<tr>
<td>100</td>
<td>96.9415</td>
<td>15.4287</td>
<td>0.0648</td>
</tr>
<tr>
<td>Mode No</td>
<td>TRAN-X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>MASS(%)</td>
<td>SUM(%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>62.5428</td>
</tr>
<tr>
<td>2</td>
<td>10.9237</td>
<td>10.9237</td>
<td>0.0011</td>
</tr>
<tr>
<td>3</td>
<td>0.0001</td>
<td>10.9238</td>
<td>6.0892</td>
</tr>
<tr>
<td>4</td>
<td>40.6911</td>
<td>51.6148</td>
<td>0.1943</td>
</tr>
<tr>
<td>5</td>
<td>10.4101</td>
<td>62.0249</td>
<td>0.9135</td>
</tr>
<tr>
<td>6</td>
<td>6.7161</td>
<td>68.7411</td>
<td>0.0001</td>
</tr>
<tr>
<td>7</td>
<td>0.2744</td>
<td>69.0155</td>
<td>10.8406</td>
</tr>
<tr>
<td>8</td>
<td>4.1203</td>
<td>73.1358</td>
<td>0.5634</td>
</tr>
<tr>
<td>9</td>
<td>0.0353</td>
<td>73.1711</td>
<td>0.0007</td>
</tr>
<tr>
<td>10</td>
<td>0.0001</td>
<td>73.1711</td>
<td>0.026</td>
</tr>
<tr>
<td>11</td>
<td>0.0005</td>
<td>73.1716</td>
<td>3.0954</td>
</tr>
<tr>
<td>12</td>
<td>0.0004</td>
<td>73.1721</td>
<td>0.4887</td>
</tr>
<tr>
<td>13</td>
<td>0.0298</td>
<td>73.2019</td>
<td>0.0387</td>
</tr>
<tr>
<td>14</td>
<td>0.0231</td>
<td>73.225</td>
<td>0.0141</td>
</tr>
<tr>
<td>15</td>
<td>0.0124</td>
<td>73.2374</td>
<td>0.1159</td>
</tr>
<tr>
<td>16</td>
<td>0.0961</td>
<td>73.3334</td>
<td>0.1523</td>
</tr>
<tr>
<td>17</td>
<td>1.2496</td>
<td>74.583</td>
<td>0.078</td>
</tr>
<tr>
<td>18</td>
<td>2.6737</td>
<td>77.2567</td>
<td>0.0734</td>
</tr>
<tr>
<td>19</td>
<td>0.0037</td>
<td>77.2604</td>
<td>1.4511</td>
</tr>
<tr>
<td>20</td>
<td>0.0873</td>
<td>77.3477</td>
<td>0.0015</td>
</tr>
<tr>
<td>21</td>
<td>0.6944</td>
<td>78.0421</td>
<td>0.0026</td>
</tr>
<tr>
<td>22</td>
<td>0.0053</td>
<td>78.0474</td>
<td>0.0403</td>
</tr>
<tr>
<td>23</td>
<td>1.6766</td>
<td>79.726</td>
<td>0.0009</td>
</tr>
<tr>
<td>24</td>
<td>0.1799</td>
<td>79.9058</td>
<td>0.2901</td>
</tr>
<tr>
<td>25</td>
<td>1.0397</td>
<td>80.9455</td>
<td>0.0255</td>
</tr>
<tr>
<td>26</td>
<td>1.5162</td>
<td>82.4617</td>
<td>0.1345</td>
</tr>
<tr>
<td>27</td>
<td>0.0326</td>
<td>82.4943</td>
<td>0.028</td>
</tr>
<tr>
<td>28</td>
<td>0.044</td>
<td>82.5384</td>
<td>0.0053</td>
</tr>
<tr>
<td>29</td>
<td>0.0045</td>
<td>82.5429</td>
<td>0.1253</td>
</tr>
<tr>
<td>30</td>
<td>0.0112</td>
<td>82.5541</td>
<td>0.1969</td>
</tr>
<tr>
<td>31</td>
<td>0.0207</td>
<td>82.5748</td>
<td>0.6192</td>
</tr>
<tr>
<td>32</td>
<td>0.1213</td>
<td>82.6961</td>
<td>0.0592</td>
</tr>
<tr>
<td>33</td>
<td>0.0107</td>
<td>82.7068</td>
<td>0.0056</td>
</tr>
<tr>
<td>34</td>
<td>1.9322</td>
<td>84.639</td>
<td>0.0483</td>
</tr>
<tr>
<td>35</td>
<td>2.4027</td>
<td>87.0417</td>
<td>0.0332</td>
</tr>
<tr>
<td>36</td>
<td>0.0052</td>
<td>87.0469</td>
<td>0.2519</td>
</tr>
<tr>
<td>37</td>
<td>0.0231</td>
<td>87.0701</td>
<td>0.013</td>
</tr>
<tr>
<td>38</td>
<td>0.012</td>
<td>87.082</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>0.0014</td>
<td>87.0835</td>
<td>0.2035</td>
</tr>
<tr>
<td>40</td>
<td>0.0935</td>
<td>87.177</td>
<td>0.0135</td>
</tr>
<tr>
<td>41</td>
<td>0.026</td>
<td>87.2029</td>
<td>0.1286</td>
</tr>
<tr>
<td>42</td>
<td>0.0028</td>
<td>87.2057</td>
<td>0.0009</td>
</tr>
<tr>
<td>43</td>
<td>0.0002</td>
<td>87.2059</td>
<td>0.0076</td>
</tr>
<tr>
<td>44</td>
<td>0.0001</td>
<td>87.206</td>
<td>1.0352</td>
</tr>
<tr>
<td>45</td>
<td>0.0002</td>
<td>87.2062</td>
<td>0.0041</td>
</tr>
<tr>
<td>46</td>
<td>0.0011</td>
<td>87.2073</td>
<td>0.0756</td>
</tr>
<tr>
<td>47</td>
<td>0.005</td>
<td>87.2123</td>
<td>0.015</td>
</tr>
<tr>
<td>48</td>
<td>0.7117</td>
<td>87.924</td>
<td>0.0779</td>
</tr>
<tr>
<td>49</td>
<td>0.121</td>
<td>88.045</td>
<td>0.4457</td>
</tr>
<tr>
<td>Mode No</td>
<td>TRAN-X</td>
<td>SUM(%)</td>
<td>TRAN-Y</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>50</td>
<td>0.0014</td>
<td>88.0464</td>
<td>0</td>
</tr>
<tr>
<td>51</td>
<td>0.5489</td>
<td>88.5953</td>
<td>0.0009</td>
</tr>
<tr>
<td>52</td>
<td>0.007</td>
<td>88.6023</td>
<td>0.2596</td>
</tr>
<tr>
<td>53</td>
<td>0.0816</td>
<td>88.6839</td>
<td>0.0091</td>
</tr>
<tr>
<td>54</td>
<td>0.0216</td>
<td>88.7055</td>
<td>0.027</td>
</tr>
<tr>
<td>55</td>
<td>0.0044</td>
<td>88.7098</td>
<td>0.0143</td>
</tr>
<tr>
<td>56</td>
<td>0.1412</td>
<td>88.851</td>
<td>0.001</td>
</tr>
<tr>
<td>57</td>
<td>0.1359</td>
<td>88.9869</td>
<td>0.0074</td>
</tr>
<tr>
<td>58</td>
<td>0.0004</td>
<td>88.9873</td>
<td>0.0002</td>
</tr>
<tr>
<td>59</td>
<td>0.0034</td>
<td>88.9907</td>
<td>0.0297</td>
</tr>
<tr>
<td>60</td>
<td>0.0003</td>
<td>88.991</td>
<td>0.0103</td>
</tr>
<tr>
<td>61</td>
<td>0.0002</td>
<td>88.9912</td>
<td>0.1033</td>
</tr>
<tr>
<td>62</td>
<td>0.0166</td>
<td>89.0078</td>
<td>0.0002</td>
</tr>
<tr>
<td>63</td>
<td>0.0362</td>
<td>89.0439</td>
<td>0.0231</td>
</tr>
<tr>
<td>64</td>
<td>0.002</td>
<td>89.046</td>
<td>0.0001</td>
</tr>
<tr>
<td>65</td>
<td>0</td>
<td>89.046</td>
<td>0.021</td>
</tr>
<tr>
<td>66</td>
<td>0.0001</td>
<td>89.0461</td>
<td>0.0273</td>
</tr>
<tr>
<td>67</td>
<td>0.1625</td>
<td>89.2087</td>
<td>0.0058</td>
</tr>
<tr>
<td>68</td>
<td>0.0098</td>
<td>89.2184</td>
<td>0.0034</td>
</tr>
<tr>
<td>69</td>
<td>0.0153</td>
<td>89.2338</td>
<td>0.1576</td>
</tr>
<tr>
<td>70</td>
<td>0.0126</td>
<td>89.2464</td>
<td>0.036</td>
</tr>
<tr>
<td>71</td>
<td>0.0174</td>
<td>89.2638</td>
<td>0.0136</td>
</tr>
<tr>
<td>72</td>
<td>0.0002</td>
<td>89.2639</td>
<td>0.1842</td>
</tr>
<tr>
<td>73</td>
<td>0.0001</td>
<td>89.264</td>
<td>0.0253</td>
</tr>
<tr>
<td>74</td>
<td>0.0609</td>
<td>89.3249</td>
<td>0.0107</td>
</tr>
<tr>
<td>75</td>
<td>0.0141</td>
<td>89.339</td>
<td>0.1918</td>
</tr>
<tr>
<td>76</td>
<td>0.0025</td>
<td>89.3415</td>
<td>0.0286</td>
</tr>
<tr>
<td>77</td>
<td>0.0333</td>
<td>89.3748</td>
<td>0.0309</td>
</tr>
<tr>
<td>78</td>
<td>0.123</td>
<td>89.4978</td>
<td>0.0313</td>
</tr>
<tr>
<td>79</td>
<td>0.6134</td>
<td>90.1112</td>
<td>0.006</td>
</tr>
<tr>
<td>80</td>
<td>0</td>
<td>90.1113</td>
<td>0.3071</td>
</tr>
<tr>
<td>81</td>
<td>0.1877</td>
<td>90.299</td>
<td>0</td>
</tr>
<tr>
<td>82</td>
<td>0.0111</td>
<td>90.31</td>
<td>0.0015</td>
</tr>
<tr>
<td>83</td>
<td>0.0572</td>
<td>90.3672</td>
<td>0.0107</td>
</tr>
<tr>
<td>84</td>
<td>0.001</td>
<td>90.3682</td>
<td>0.1771</td>
</tr>
<tr>
<td>85</td>
<td>0.0017</td>
<td>90.3699</td>
<td>0.0058</td>
</tr>
<tr>
<td>86</td>
<td>0.1289</td>
<td>90.4988</td>
<td>0.0012</td>
</tr>
<tr>
<td>87</td>
<td>0.0455</td>
<td>90.5443</td>
<td>0</td>
</tr>
<tr>
<td>88</td>
<td>0.0021</td>
<td>90.5464</td>
<td>0.1054</td>
</tr>
<tr>
<td>89</td>
<td>0.0019</td>
<td>90.5483</td>
<td>0</td>
</tr>
<tr>
<td>90</td>
<td>0.0001</td>
<td>90.5483</td>
<td>0.0098</td>
</tr>
<tr>
<td>91</td>
<td>0.0006</td>
<td>90.549</td>
<td>0</td>
</tr>
<tr>
<td>92</td>
<td>0.0001</td>
<td>90.549</td>
<td>0.0233</td>
</tr>
<tr>
<td>93</td>
<td>0.0022</td>
<td>90.5512</td>
<td>0.0001</td>
</tr>
<tr>
<td>94</td>
<td>0.0024</td>
<td>90.5536</td>
<td>0.2178</td>
</tr>
<tr>
<td>95</td>
<td>0.0127</td>
<td>90.5663</td>
<td>0.0099</td>
</tr>
<tr>
<td>96</td>
<td>0.1646</td>
<td>90.7309</td>
<td>0</td>
</tr>
<tr>
<td>97</td>
<td>0.0438</td>
<td>90.7747</td>
<td>0</td>
</tr>
<tr>
<td>98</td>
<td>0.0025</td>
<td>90.7771</td>
<td>0.0202</td>
</tr>
<tr>
<td>99</td>
<td>0.003</td>
<td>90.7801</td>
<td>0.0176</td>
</tr>
<tr>
<td>100</td>
<td>0.0016</td>
<td>90.7817</td>
<td>0.0062</td>
</tr>
</tbody>
</table>
In the next pictures are showed the deformed shape of the most important modes.

Picture.38.- Mode 1

Picture.39.- Mode 2
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MATHEMATICAL MODEL

Picture.40.- Mode 4

Picture.41.- Mode 5
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
MATHEMATICAL MODEL

Picture.42.- Mode 7

Picture.43.- Mode 13
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MATHEMATICAL MODEL

Picture 44. - Mode 14

Picture 45. - Mode 18
7. **SEISMIC BEHAVIOR OF THE STRUCTURE**

The study of seismic behavior of the structure was executed with a linear dynamic analysis applying design spectrum of EN 1998 shows in the previous chapter. Was analyzed the seismic behaviour of transversal, longitudinal and vertical direction.

With reference to the study of seismic behaviour of monument, it’s important to underline that a finite element model do not provide informations about local collapses and detachments related to possible local decay of masonry or bad connection of walls.

In the following paragraphs the results of the seismic analysis carried out considering the action of earthquake in the transversal, longitudinal and vertical direction are reported.

The deformed shape and tensile stresses of structure are showed considering the combinations of earthquake action and self weight with combined factor of NTC 2008 (Italian code)

The direction combination of seismic action are the following:

- **TRANSVERSAL SEISMIC COMBO:** $1*D + 1*E_Y + 0.3*E_X + 0.3*E_Z$
- **LONGITUDINAL SEISMIC COMBO:** $1*D + 1*E_X + 0.3*E_Y + 0.3*E_Z$
- **VERTICAL SEISMIC COMBO:** $1*D + 0.3*E_X + 0.3*E_Y + 1*E_Z$

where D is the self weight load, $E_X$, $E_Y$ and $E_Z$ represented the seismic action in the axes directions.

To take into account all the possible earthquake direction all seismic action are combined between them with the sign – and +.
7.1.1. **TRANSVERSAL SEISMIC COMBO:** 1*D + 1*E\textsubscript{Y} + 0,3*E\textsubscript{X} + 0,3*E\textsubscript{Z}

The transversal direction of seism is the most critical one for the global structure stability because of the less presence of contrasts’structure in this direction. Those structures must resist to the seismic forces associated to the acceleration of large masses in the central part of the Cathedral.

The following pictures shows that main displacements are localized where the largest masses are concentrated at the highest elevation, as in the case of dome, drum and central arches.

Also the external walls of structure are interested by important displacements and local bulges in the direction of seism.

The plumb line deviation of the Southern and Northern Facades are probably associated not only to the thrust of central arches and vaulted structures but also to action of historical seismic events.

The action of a transversal earthquake contributes to increase the stresses in the structural elements already interested by an high level of stresses in the static conditions.

In the followings figures it’s shows the maximum displacement of the structure in seismic direction.

The dynamic linear analysis shows a positive displacement if these displacements are concordant with positive axes. In fact to correctly evaluate behaviour of structure under seismic action is necessary shows a maximum displacements (concordant with positive Axes) and a minimum displacements (not concordant with positive axes).
Picture.46.- Max Deformed shape, top view (COMBO SEISMIC +Y)

Picture.47.- Min Deformed shape, top view (COMBO SEISM+Y)
Object: Cathedral of Svetitskhoveli - Mtskheta

Mathematical Model

Picture 48.- Max Deformed shape, isometric view (COMBO SEISM+Y)

Picture 49.- Min Deformed shape, isometric view (COMBO SEISM+Y)
OBJECT: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MATHEMATICAL MODEL

Picture.50.- Max Deformed shape, view from West side (COMBO SEISM+Y)

Picture.51.- Min Deformed shape, view from West side (COMBO SEISM+Y)
As shows in the below images the seismic behaviour is the same in the positive and negative direction because the calculation model is symmetric. The maximum displacement is approximately 43 mm in summit of roof’s dome.

In particular it’s interesting to observe a maximum value of compressive vertical stress of about 3.6 MPa at the base of a main pillar that supported the dome and a value of maximum tensile stress of 1.07 MPa at the arch key.

Those results suggest that the action of the earthquake may be determine to reach the collapse in some important structural elements as the pillars (possible crushing and overturning) and the main arches (possible collapse due to the opening in the arch key).

The analysis of the central part of the Cathedral is very important to study the seismic behaviour of the structure. The dome fell down as a results of the devastating earthquake in Georgia of the 1283 and it was repaired in the first half of the 14\textsuperscript{th} century. The action of transversal seism causes a considerable increasing of the maximum compressive stresses $\sigma_{zz}$ at the base of the pillars of about the 80\% (3.6 MPa against the 2.00 MPa of the dead load case).
This increasing can be very dangerous considering the height level of stress of those pillars also in static condition.

The maximum tensile stresses on transversal seism is of the maximum tensile stresses at the key of main arches respect static conditions. Despite a linear elastic constitutive model is not appropriate to calculate the real tensile stresses in a masonry structure, the above mentioned increase may get worse the phenomenon opening of cracks in the arch keys of with consequent possibility of collapse of all the central portion of the Cathedral.

Also the cracks interesting the drum area are related to mechanism of deformation of main arches, due to the not well countered thrust of those structures.

The mechanism previously described characterizes the behaviour of the structure also in static condition and it is clearly more dangerous for the structure stability during the seismic action.
Object: CATHEDRAL OF SVETITSKHOVELI - MTSKHETA

MATHEMATICAL MODEL

Picture 54. - Maximum and minimum tensile stresses of central arches, bottom and up view (COMBO SEISM+Y)
Picture 55.- Cracks in the drum area
7.1.2. **LONGITUDINAL SEISMIC COMBO:**  

\[ 1^*D + 1^*E_x + 0.3^*E_y + 0.3^*E_z \]

The longitudinal seismic action is less critical for displacements because this direction have a greater horizontal stiffness due to greater longitudinal dimension of the structure and due to presence of more pillars than transversal direction that are better contrasted in the longitudinal direction of the Cathedral.

As expected the maximum displacements obtained by the analysis are considerable lower with respect to the case of transversal seismic.

Also in the case of longitudinal seismic action the main displacements are localized in the dome, drum and central arches.

The longitudinal seismic action, as in transversal direction, contributes to increase the stresses in the structural elements interested by high stresses in the static conditions.

In particular a maximum value of compressive vertical stress of 3.77 MPa is reached at the base of a main pillar.

In the below figures is reported the value of displacements on the structure under seismic action.

![Diagram of cathedral structure with displacements](image)

*Picture.56.- Max Deformed X shape, top view (COMBO SEISM+X)*
OBJECT:
CATHEDRAL OF SVETITSKHOVELI - MTSKHETA
MATHEMATICAL MODEL

Picture.57.- Min Deformed X shape, top view (COMBO SEISM+X)

Picture.58.- Max X Deformed shape, isometric view (COMBO SEISM+X)
Object: Cathedral of Svetitskhoveli - Mtskheta

Mathematical Model

Picture 59. Min X Deformed shape, isometric view (COMBO SEISM+X)

Picture 60. Max X Deformed shape, view from South side (COMBO SEISM+X)
The deformed shape of the longitudinal seismic combo shows that the most important displacements are always located in the dome. The maximum displacements is 28.3 mm on the pot of the dome.

The longitudinal and transversal displacements ratio is 1.5, confirming the greater horizontal stiffness of the longitudinal direction than the transversal direction.
Also in this seismic direction is shown the same particular figure of the support structure of the dome.

In the following pictures is shown the trend of the vertical stresses on the support structure of the dome.

Picture.62.- Max and Min X Deformed shape, central pillars (COMBO SEISM+X)

Picture.63.- Max and Min Vertical stress ZZ of central pillars (COMBO SEISM+X)
The action of seism causes an important increasing of the maximum stresses $\sigma_{zz}$ at the base of the pillars of about the 88% (3.77MPa against the 2.00 MPa of the dead load case).

Finally is show the tensile and compression stress in the arch key for the longitudinal seism combo.

![Diagram](image1.png)

Picture.64.- Max tensile stresses of central arches, bottom view (COMBO SEISM+X)

![Diagram](image2.png)

Picture.65.- Min tensile stresses of central arches, top view (COMBO SEISM+X)

The maximum tensile stress at the arch keys is 1.72, a very high strength level.

That result confirm the dangerous of a seismic action on the structure.
7.1.3. **VERTICAL SEISMIC COMBO:** \[ 1*D + 0.3*E_x + 0.3*E_y + 1*E_z \]

The vertical direction of seismic action has been modelled to consider the sussultatory component of earthquake.

This kind of action increase and decrease the vertical load on the structure, with particular attention to the component that increase the vertical compression stress.

Generally this seismic combination does not generate high increase of tension on the structure.

In the following figure is reported the trend of displacements. Some picture doesn’t report the maximum trend of displacements because it’s not interesting.

![Picture 66. - Min Deformed Z shape, isometric view (COMBO SEISM+Z)](image-url)
The maximum displacements in concentrate on the top frontal of the dome. This rotation effect of the structure of the dome had highlighted in the self weight analysis for the different bending stiffness of the pillars. The frontal pillars that supported the dome, nearest at entrance of the Cathedral, has less bending stiffness than back pillars. This effect is due to the presence of a contrast walls.
Also in this seismic direction is shows same particular figure of the support structure of the dome.

In the following pictures is shows the trend of the vertical stresses on the support structure of the dome.

Picture.68.- Max and Min Z Deformed shape, central pillars (COMBO SEISM+Z)

Picture.69.- Max and Min Vertical stress ZZ of central pillars (COMBO SEISM+Z)
In this case the increasing of the maximum stress $\sigma_{zz}$ at the base of the pillars of about the 60% (3.21 MPa against the 2.00 MPa of the dead load case).

Finally is show the tensile and compression stress in the arch key for the vertical seismic combo.

The maximum tensile stress at the arch keys is 1.50 Mpa, a very high strength level. This is the prove that vertical seismic direction is less importance for the stresses on the structure.
8. STRUCTURAL SAFETY

The code using in structural safety is NTC 2008 and “Linee Guida per la valutazione e riduzione del rischio sismico del patrimonio culturale allineate alle nuove Norme tecniche per le costruzioni (D.M. 14 gennaio 2008)” that are Italian codes for masonry structure and historical monument.

The design strength is calculated by a confidential coefficient (Fc) that holds between 1 and 1.35. These coefficients are multiplied by another design material coefficient (γm) from Italian code that holds between 2 and 3.

The result of these multiplications is the reduce factor for masonry strength. Thanks to the investigation on Cathedral the confidential factor Fc is 1.18 and for the safety on static load the material factor is 3.

The below table shows the value of Fc:

\[ Fc = 1 + Fc1 + Fc2 + Fc3 + Fc4 \]

Picture.72.- Confidential Factor (Italian Codes)
8.1. **SELF WEIGHT LOAD**

As expected the maximum stresses are located at the base of central pillar where the model provides a value of about 2.0 MPa. Those maximum value is located in a very limited portion of the base of two of the central pillars, while more considerable areas of the pillars reach values of stress SZZ of about 1.5-1.7 MPa.

Considering the coefficient of combination SLU provides by the NTC 2008 (Italian code) for structural permanent loads equal to 1.3 is obtained:

\[ 1.6 \text{ MPa} \cdot 1.3 = 2.10 \text{ MPa} \]

This value was compared with the value of strength of the masonry considering a safety factor of 3.54. For this reason the value of strength of masonry is \(3.5 \text{ Mpa} / (3 \cdot 1.18) = 0.98 \text{ Mpa}\)

The verification is satisfied when the strength material is greater of the applied action.

\[ 0.98 \text{ MPa} < 2.10 \text{ MPa} \]

Hence the check is not satisfied considering the strength of the homogenous material.

For the Italian code the verification is not satisfied, shows that has not been reached the structural safety.

8.2. **SEISMIC LOAD**

As expected the maximum stresses are located at the base of central pillar where the model provides a value of about 3.77 MPa. Those maximum value is located in a very limited portion of the base of two of the central pillars, while more considerable areas of the pillars values of stress SZZ of about 2.7 MPa.

Considering the coefficient of combination SLV provides by the NTC 2008 (Italian code) for structural permanent loads equal to 1 is obtained:

\[ 2.7 \text{ MPa} \cdot 1 = 2.70 \text{ MPa} \]
This value was compared with the value of strength of the masonry considering a safety factor of 2.36. For this reason the value of strength of masonry is 3.5 Mpa/(2*1.18) = 1.48 Mpa

The verification is satisfied when the strength material is greater of the applied action.

\[ 1.48 \text{ Mpa} < 2.70 \text{ Mpa} \]

Hence the check is not satisfied considering the strength of the homogenous material.

For the Italian code the verification is not satisfied, shows that has not been reached the seismic structural safety.
8.3. **LOCAL MODEL FOR INNER PILLAR**

Through the study of the history of the Cathedral, the videoendoscopic investigation and the survey the new pillars were built around the old ones. In the following pictures shows the presence of old pillar with the new pillar around.

![Diagram of Cathedral of Svetitskhoveli in Mtskheta](image)

**Picture.73.- Inner pillar**
The old horizontal structures (vaults and arches) and then much vertical load discharge over old pillar. In the mathematical model the pillars are modelling as the new section of pillar that, in this specific case, is approximately 5 m$^2$. The old pillar area is 1.14 m$^2$. The different area between new and old pillar involves greater compression tension. For this reason was considered necessary calculate with a local model the greater compression tension, assuming that all the load discharge on old pillar. This is favor of safety assumption because is possible that a part of load discharge over new pillar. In the following table is reported the doings calculations to better understanding the real tension state of the pillar

<table>
<thead>
<tr>
<th>Mathematical model compression tension</th>
<th>Local model compression tension</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_z = 4450$ kN</td>
<td>$F_z = 4450$ kN</td>
</tr>
<tr>
<td>$A_{p_model} = 5$ m$^2$</td>
<td>$A_{inner_pillar} = 1.14$ m$^2$</td>
</tr>
<tr>
<td>$\sigma_{P_model} = 0.89$ MPa</td>
<td>$\sigma_{P_inner_pillar} = (A_{p_model} / A_{inner_pillar}) \cdot \sigma_{P_model}$</td>
</tr>
<tr>
<td></td>
<td>$\sigma_{P_inner_pillar} = 3.9$ MPa</td>
</tr>
</tbody>
</table>

As shows by the calculation the compression on the pillar is 3.9 Mpa respect the compression of mathematical model that is of 0.89 Mpa.

This new value of compression (3.9 Mpa) is a very high result for masonry material, in fact the compression strength of masonry material was estimate on 3.5 Mpa.

The photographic survey shows a evident compression crack on the base of old pillar that proves the exceeded of compression tension of material on the base of old pillar.

The following image shows the compression crack.
9. CONCLUSIONS

This technical document includes the assessment of the mechanical behavior of the Svetitskhoveli Cathedral in Mtskhet.

A structural analysis implementing a Finite Elements Model was performed to evaluate the vulnerability assessment and risk. The model implemented is a linear elastic model where the geometric characteristic of the fabric is supposed made from a continuous elastic material.

Despite an elastic model is a simplification of the real constitutive law of the masonry, it is very useful to study the global behavior of structure and to evaluate the possible mechanism of damaging or collapse.

The analysis shows that the state of crack interesting the Cathedral is mainly related to the presence of the heavy dome.

The high weight of the dome cause the deformation of the central arches, pillars and external walls, primarily in transversal direction (X direction). The considerable out of plumbs observed in the central pillars is related to the not countered thrust of arches particularly in transversal direction.

The seismic analysis carried out show that the structure is weaker toward the action of earthquakes in the transversal direction. Those action contribute to increase the stresses in the structural elements already interested by an high level of stresses in the static conditions, in particular the base of pillars interested by high vertical loads and the tensile stresses in arch key.

The study of the static and seismic behaviour suggests, in order to improve the safety level of the monument with some kind of strengthening below reported.
9.1. DRUM AND DOME OVALIZATION

The seismic analysis prove that the base of the drum undergoes differential displacements due to different bending stiffness of the support pillars. This effect causes a ovalization of the base of drum that produces an increment of tensile stress.

The presence of important crack on the drum suggests that further earthquake can create more damage compromising the structural safety.

The following pictures shows the ovalization effect and the present crack on drum.

![Picture of drum ovalization and crack]

For these reason is important create a base reinforce system to decrease the differential deformation on seismic action.

Was created a global finite element model in witch was modelled the base wood stiffening to shows the upgrade of structural behaviour. The next image shows the modellation of wood stiffening on the base drum.
Picture 77.- Wood base drum stiffening

In the newt picture represent with the same scale factor the difference of ovalization between the drum without stiffening and with stiffening.

Picture 78.- Displacement without and with wood stiffening

The next table shows a percentage confront between the structure’s displacements.
As shows by the table there is an important upgrade of maximum displacements of the drum and the differential displacements. The reduction of maximum displacement is 58%, while the reduction of differential displacements is 25%.
9.2. **INCREMENT COMPRESSIVE STRESS FOR SISMIC LOAD**

The high self weight stress combined with seismic actions produces an elevate stress state that increased the compression stress on pillars. The following picture shows this effect on pillars.

![Picture](image)

Picture 80.- Increasing of compression tension

The self weight load doesn’t generate high value of compression stress, while seismic action produce an important widespread zone of maximum compression tension. Most likely expulsion of face is due to a past earthquake and a local effect of external face.

For this reason is necessary intervene with a circumferential boundary that improve the strength of masonry and avoids further damage of external face.

The possible increment of compression and expulsion of external face can be a probably behaviour of all Cathedral’s pillars. While a bounding obtained with active rebar or a circumferential boundary system to increasing masonry strength is suggested.
9.3. **LOCAL TRASVERSAL WALL MODEL**

The global model in seismic condition show the increment of tensile stress on crown arches highlighted in below figure.

To avoid the extraction of stone from the crown arches is necessary block the stone and increase the local stiffness of the arches. The figure below shows the increment of tensile stress and the deformation of the wall in seismic condition.

Picture.81.- Horizontal displacements for seismic action

Increasing the arches stiffness with steel plate is possible decrease the tensile stress on crown arches and avoid the extraction of stone.
9.4. ARCHES SUPPORTED DRUM AND DOME VERTICAL REBAR

Static and mostly seismic analyses shows a very high values of tensile tension on crown of arch that supports the dome and the drum.

The followings pictures shows the value of traction that reaches, in seismic condition, 1.7 MPa.

Picture.82.- Value of tensile stress on arch under self weight load

Picture.83.- Value of tensile stress on arch under seismic load
Clearly it isn’t a admissible value for this kind of masonry. This value is a result of an elastic model and should not be considered the absolute value but the increasing of tensile stress on crown of arch. The real tensional state will never reach this high value of tensile stress but will increase the stress compression value with the creation of crack on tensile zone of arch. These cracks compromises the static safety of support structure of the dome and may cause the extraction of crown stone.

To avoid this phenomenon, especially in crown of arch, is necessary constrain the stone with passive rebar.
Project Documentation of Temporary Protective Roofing for Adobe Brick Walls

2013
Armaztsikhe-Bagineti archaeological site
Archaeological excavations
1. INTRODUCTION

<table>
<thead>
<tr>
<th>State Party</th>
<th>Name of the Property</th>
<th>Date of Inscription</th>
<th>Criteria</th>
<th>Organization responsible for the preparation of the report</th>
<th>Date of Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>Historical Monuments Mtshketa</td>
<td>1994</td>
<td>C (iii, iv)</td>
<td>National Agency for Cultural Heritage Preservation of Georgia</td>
<td>2014</td>
</tr>
</tbody>
</table>

2. SIGNATURE ON BEHALF OF STATE PARTY

Marine Mizandari

First Deputy Minister of Culture and Monuments Protection of Georgia

3. STATEMENT OF SIGNIFICANCE

AS PROVIDED BY STATE PARTY IN THE NOMINATION DOSSIER

"City-museum, architectural reserve, Mtshketa is a multi-layered monument, testifying to the great scope of building activity and high culture of the country. Preserved architectural monuments and unearthed archaeological material testify to the high artistic value of building and minor arts in various epochs, beginning from the 2nd mill. B.C. to today. The architectural monuments of Mtshketa, being stage-making in the development of Georgian architecture are at the same time extremely significant for the study of the medieval architecture of the whole Christendom. Besides they are striking examples of the unity of architecture with the surrounding landscape. Of special value from the artistic and historical points of view are the monuments of monumental painting (mosaic floor in "Dionysius Maison" in Dzalisa, 2nd c. A.D.) and metalwork (goldsmithery) discovered in Mtshketa. Special place in Semitic epigraphic is occupied by Armazi inscriptions, giving vast valuable data for the study of the written language in general and making it possible to deal with the origin of Georgian written language anew"