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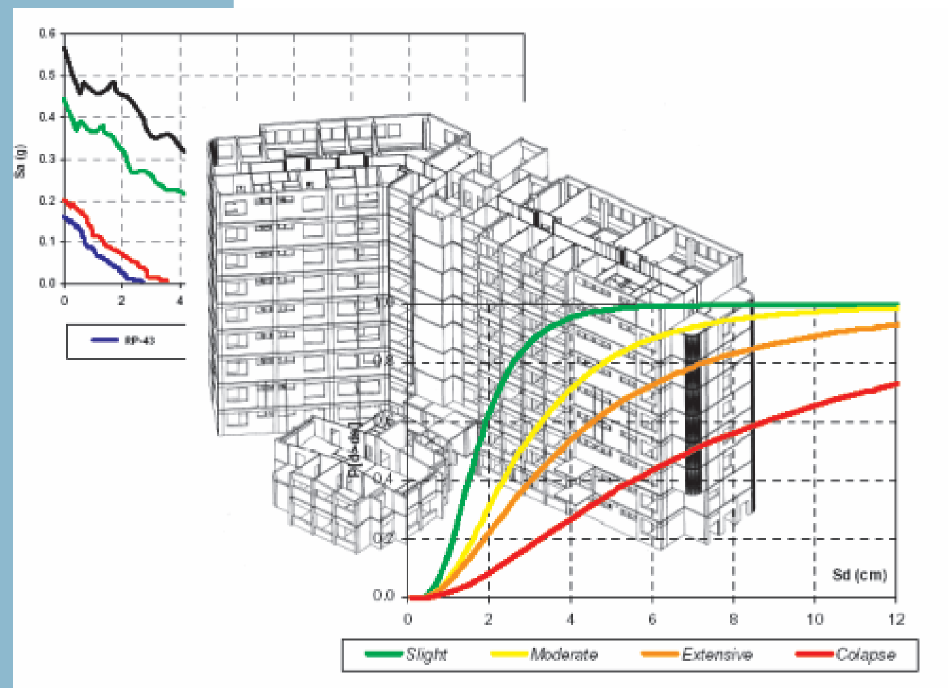

Seismic Vulnerability Assessment of a Key Health Facility in The former Yugoslav Republic of Macedonia

- a handbook -

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Preface

There is a widely held expectation that hospitals and other health facilities are prepared to deal with any crisis. This perception in general may be valid, however past events have demonstrated that they may be particularly vulnerable to earthquakes and therefore rendered unable to respond. The seismic vulnerability of hospitals, if compared to other buildings and installations of equal size and construction, is more complex since it is generated by their structural, functional, technological and administrative/organizational performance.

A reliable and comprehensive hospital vulnerability assessment can only be carried out taking into account all three main vulnerability categories.

Considering the primary issues proceeded from the World Conference on Disaster Reduction held in January, 2005 in Kobe, Japan (Session 4.2, Thematic cluster 4) regarding vulnerability reduction in health facilities, the World Health Organization, Regional Office for Europe, (WHO-EURO) Copenhagen, Denmark and the Section for Risk, Disaster Management and Strategic Planning (RDM) at the Institute of Earthquake Engineering and Engineering Seismology (IZIIS-Skopje), University "St. Cyril and Methodius", Skopje launched integral Health Facility seismic vulnerability Evaluation method (HVE method). It is suitable to perform preliminary (qualitative/quantitative) vulnerability assessment, to identify the possible weak elements in the facility and main vulnerability agents as well as to decide for prioritizations of the necessary further "in-depth" investigations.

As a pilot study, the HVE method is successfully implemented to Paediatric Clinic, Clinical Centre, Skopje, considering its importance in the health-care system of the country as well as the occupancy type – children of all ages, ranging from newborns to 14 years. The method is extended with detailed seismic vulnerability assessment including ambient vibration measurements.

Institute of Earthquake Engineering and Engineering Seismology, University "St. Cyril and Methodius", Skopje, extend its most sincere gratitude to WHO - Regional Office for Europe for recognizing the need for performing such activity as well as the financial aid provided for its execution. Considering the confirmed effectiveness and reliability of the HVE method, the authors believe that it will be used to perform complex vulnerability evaluation to other important health-care facilities in The former Yugoslav Republic of Macedonia and the wider region.

May 20, 2006

Dr Goran S. TRENDAFILOSKI
Principal project investigator

Foreword

"Seismic vulnerability assessment of a key health facility in The former Yugoslav Republic of Macedonia"

The World Health Organization Regional Office for Europe is, within the framework of "Matching services to country needs" and in line with the World Health Organization global strategic priorities of "Health Action in Crisis", committed to assist its 53 member states in strengthening the capacity of their health systems to respond to future crisis situations.

The health sector in general and hospitals and health facilities in particular, play an essential role in the response to all kinds of natural or man-made disasters, as the protection of human beings and their health is of primary importance in all emergencies.

Lessons learnt from previous crises clearly indicate that sound preventative efforts pay off in subsequent emergencies. Preparedness programmes are more effective when they are designed and implemented as a continuous process, based on analysis of hazards and vulnerabilities. Ministries of health, require political support, including appropriate financial and human resources to ensure that the health system is prepared for and able to cope with disasters, with reliable hospitals and health facilities being of utmost importance to provide essential services to victims.

The Disaster Preparedness and Response programme of the WHO Regional Office for Europe, is committed to cooperate closely with WHO Member States and other stakeholders to achieve tangible results at country level. Reliable health facilities – as functioning safe havens for disaster victims in the aftermath of a crisis – have been identified as a potential indicator for the effectiveness of national preparedness programmes. The international Kobe conference in early 2005 and the resulting Hyogo framework for action have highlighted the importance of "hospitals (being constructed in a way that makes them) safe from disasters".

Hospitals in particular must be designed to fulfil security and performance standards that will not only ensure the safety of the occupants (patients and medical staff) at the time of an earthquake, but will also enable a facility to be functional in the aftermath and provide medical care to victims in the affected region.

This report has been developed with the assistance of the Institute of Earthquake Engineering and Engineering Seismology to promote the health facility seismic vulnerability evaluation method (HVE method) through the assessment of a key health facility in The former Yugoslav Republic of Macedonia.

Dr Gerald Rockenschaub
Regional Adviser, Disaster Preparedness & Response
WHO Regional Office for Europe

1. Introduction

Experience from the past earthquakes that has occurred throughout the world noticeably showed that the health care facilities in the affected region are the key part of the immediate response capability. The ability of the community to cope with the consequences of an earthquake significantly depends on damages inflicted on major health care facilities. The question is how these facilities will be able to perform after an earthquake and how will their performance affect the community's emergency response capability.

Although health care facility construction is similar to that of other buildings, the size, occupancy and purpose of these buildings dictate that seismic safety be given special attention. Hospitals in particular must be designed fulfilling the safety and performance demands for such a facility that will provide not only the safety of the occupants (patients and medical staff) at the time of an earthquake, but also will enable that the facility be functional in the aftermath and provide medical care to the victims in the affected region.

Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must consider all aspects of facility vulnerability. A reliable and comprehensive hospital assessment can only be carried out taking into account all three main vulnerability categories in the stated order: 1) structural; 2) non-structural; and, 3) administrative/organizational vulnerability.

Various methods for health facility vulnerability assessment exist and they differ in expenditure, complexity and precision. Most of them threat each vulnerability category separately and usually, for their implementation, sound engineering background, software and comprehensive data set are required. Due to the incorporated vulnerability models some of the methods are spatially oriented i.e. prepared for certain regions, and can be straightforward applicable to other regions with similar building typology only.

Considering the primary issues proceeded from the World Conference on Disaster Reduction held in January, 2005 in Kobe, Japan (Session 4.2, Thematic cluster 4) regarding vulnerability reduction in health facilities, the World Health Organization, Regional Office for Europe, (WHO-EURO) Copenhagen, Denmark and the Section for Risk, Disaster Management and Strategic Planning (RDM) at the Institute of Earthquake Engineering and Engineering Seismology (IZIIS-Skopje), University "St. Cyril and Methodius", Skopje to launched Health facility seismic Vulnerability Evaluation method. It is suitable for performing preliminary (qualitative/quantitative) vulnerability assessment, identifying the possible weak elements in the facility and main vulnerability agents as well as deciding for prioritizations of the necessary further "in-depth" investigations.

As a pilot study, the HVE method is implemented to Paediatric Clinic, Clinical Centre, Skopje, considering its importance in the health-care system of the country as well as the occupancy type - children of all ages, ranging from newborns to 14 years.

The general information regarding Paediatric clinic including its: 1) architectural and structural characteristics; 2) present state of the facility and maintenance; 3) site geological conditions and sesimicity are presented in details in Chapter 2.

The Chapter 3 presents the evaluation of the structural, non-structural and administrative vulnerability of the Paediatric clinic using the HVE method.

The seismic structural vulnerability assessment is presented in Chapter 4. It includes: seismic demand estimation, ambient vibration measurements and estimation of the damageability and facility performance. This chapter also gives a short review of the possible short and long term mitigation measures.

The conclusions and recommendations are given in Chapter 5 of the report and list of used references in Chapter 6.

Appendix A contains plans and cross section of the Paediatric clinic.

The photos are presented in Appendix B.

Appendix C contains the health facility vulnerability evaluation forms for the Paediatric clinic such as: 1) HVE-001 form for health facility general evaluation; 2) HSVE-002 form for structural vulnerability evaluation; 3) HNVE-001/1, HNVE-001/2 and HNVE-001/3 forms for non-structural vulnerability evaluation; and, 4) HOVE-001/1 and HOVE-001/2 forms for A/O vulnerability evaluation.

2. Paediatric clinic, clinical centre – Skopje

2.1 General information

The Paediatric clinic is part of the University Hospital Campus (UHC) that incorporates 25 clinics (18 clinics of the Clinics Centre Skopje (CCS) and 7 clinics of Stomatology Clinics Centre), Faculty of Medicine and Faculty of Stomatology, Institutes of the Faculties of Medicine and Stomatology, National (republic) and City Institute for health protection as well as other administrative and utility services and is the most essential health care centre in The former Yugoslav Republic of Macedonia. As a part of the Clinical Centre Skopje, the Paediatric Clinic provides high level professional health care for the patients from all parts of the country. It is situated at the southern edge of the UHC location (Fig. 2.1) [8].

Paediatric clinic is organized in several departments (intensive care, neonatology, pulmonology, neurology, psychiatry, immunology, oncology, etc.) equipped with professional staff and equipment. A total number of 339 employed (75 doctors, 191 nurses and other medical staff, 18 administrative workers and 55 technical staff) take care of 200–250 patients a day, out of which 20–25 patient are accepted for hospital treatment. Patients are children of all ages, ranging from newborns to 14 years. Inpatients that are younger than three years are accompanied by one of their parents.

2.2 Architectural and structural characteristics

The building that accommodates the Paediatric clinic was designed and constructed according to the functional and organizational needs of a health care facility that has quite significant number of patients daily and provides different medical services (in and out patients, diagnostic imaging, laboratory, etc.).

The whole facility is composed of three blocks - two wings A and B and a central block C (Appendix A). The two wings accommodate different medical services and administration, while the central block mainly serves as communication from wing to wing and accommodates the elevators and stairs.

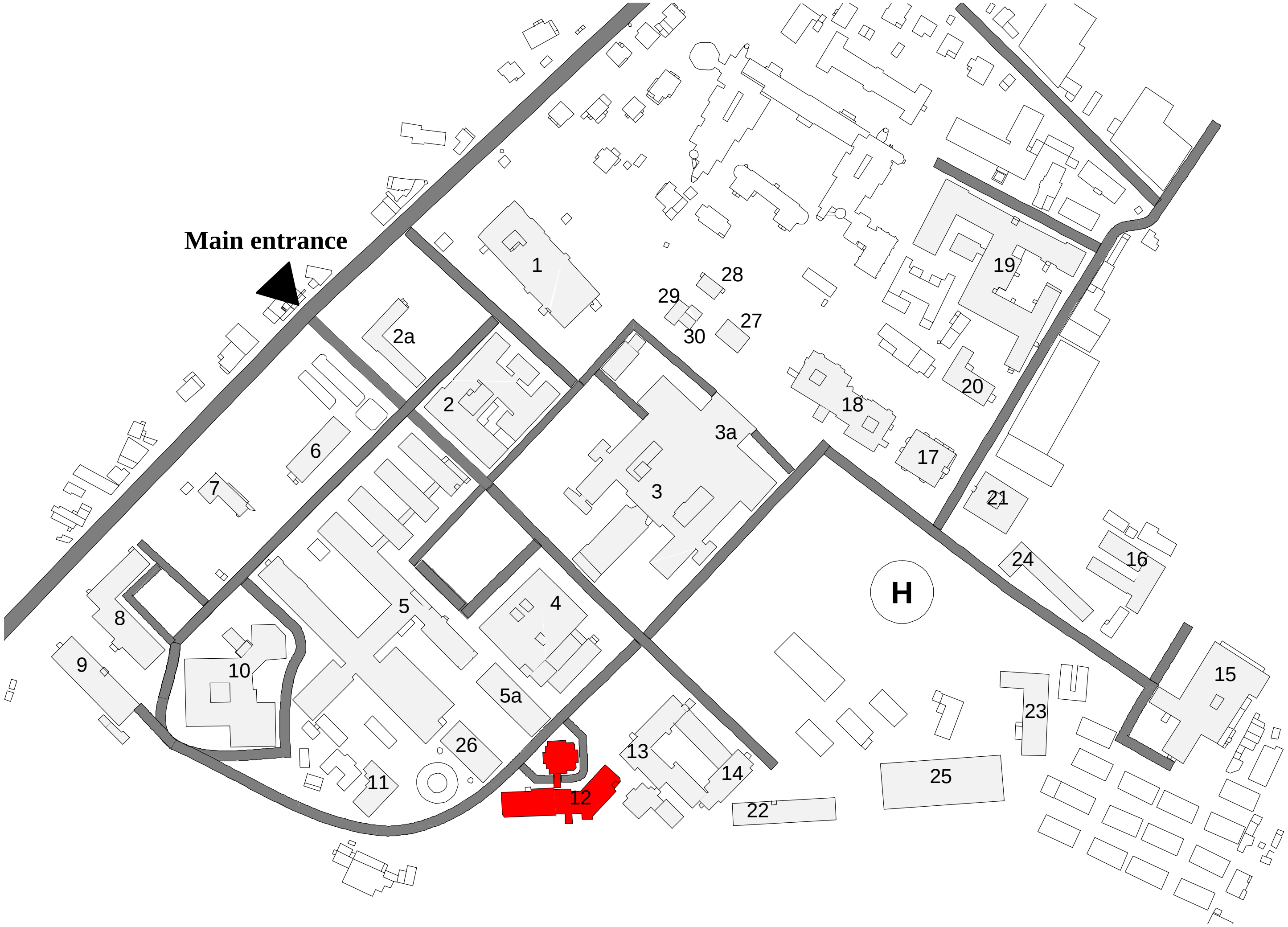
The building has a basement, ground floor and 7 floors, with total net area of 7100m^2.

The basement accommodates the utilities (electricity back up system, technical gases control unit, central heating control unit, water supply control valve, electrical power substation, and laundry facility), archive, staff dressing room, kitchen, storage, etc.

The ground floor accommodates the Intensive Care Unit (block B), and the medical services provided for outpatients (Appendix A) and reception (block A).

Floors one to six accommodate various hospital departments, laboratories and administration such as:

1st floor – Hemathology and oncology;
2nd floor – Endocrinology, genetics and cardiology;
3rd floor – Pulmonology;
4th floor – Gastroenteropathology and immunology
5th floor – Neurology and Psychophysiology;
6th floor – Neonatology and newborn’s metabolism
7th floor – Laboratories and administration



LEGEND

1 Institute for radiotherapy
2 Obstetric and gynaecology clinic
2a Obstetric and gynaecology – out patients department
3 Surgical clinic (old building)
3a Surgical clinic (new building)
4 Institute for radiology
5 Clinic for internal diseases
5a Clinic for internal diseases out patients department
6 Institute for pathophysiology and nuclear medicine
7 Fluorographic service
8 Clinic for physiology
9 Institute for forensic medicine
10 Cardiology clinic
11 Neurology clinic
<u>12 Paediatric clinic</u>
13 Institute for Transfusiology
14 Haematology clinic
15 Clinic for infectious diseases
16 Faculty for pharmacy
17 Clinic for maxilla-facial surgery
18 Stomatology clinic
19 Institutes
20 Dean's office
21 Administrative building
22 Technical support office
23 Laundry facility
24 Garage
25 Hospital kitchen
26 Hot water plant
27 Cooling facility
28 Technical gasses station
29 Electric power station (T.S)
30 UPS facility

Communication routes

Fig. 2.1 Location of the Paediatric clinic within Clinical centre

Organization of the space in both wings is the same. There is a central corridor with rooms with various functions on both sides (Appendix B). There are several types of patient rooms (Appendix B), according to the age of the patients and whether the patients are accompanied by a parent. Some of the rooms have glass partitions (Appendix B) in order to facilitate the medical staff control over the patients (children).

The allocation, the spatial distribution and organization of the space of each department is defined by the services it provides.

The Paediatric Clinic is designed in 1979 by the Construction Company “Beton”. The construction of the building is completed in the period 1980-1984 and the building itself was put in effect in 1985 [2].

The building is separated by expansion joints of 12 cm. The average story height is 3.2 m and the construction module is 6.4 m.

The main bearing system of the blocks A and B are RC frames and RC shear walls of the block C. The dimensions of the columns are 50/70 cm and the beams 50/60 cm. The RC shear walls are 25 cm thick. The floors are cross-wise RC slabs with height 15 cm.

The foundation is performed using solitaire footings (4.2/4.2 m) placed on gravel layer and connected with RC foundation beams with dimensions 50/70 cm.

The seismic forces are calculated according to 1964 Code[1]. This code provided the technical regulations for design and construction of buildings in seismic regions of maximum intensity VII, VIII and IX on the Mercalli-Cancani-Sieberg (MCS) seismic intensity scale. The seismic zonation of Macedonia was defined by official Seismological Map of Yugoslavia published by the Seismological Institute of FPR Yugoslavia in 1950.

The 1964 Code distinguish the building categorization by use and importance, attributing certain building category coefficients that are implicitly incorporated in the coefficients of design seismicity Kc. Accordingly, hospital buildings are classified into Category I buildings, for which the seismic intensity coefficient shall be increased by factor 2 for seismic regions of intensity I = VII - VIII^o MCS, and by factor 1.5 for regions with maximum expected intensity of I =IX^o MCS.

The Paediatric Clinic is designed according to the above principles adopting good soil conditions. The seismic design spectra (seismic shear base coefficient) is presented in Fig. 2.2. The estimated predominant periods of vibration according to which the seismic forces are calculated are presented in Table 2.1 [2].

Table 2.1 Estimated predominant periods of vibration (ref: [2])

Part	Longitudinal (sec)	Transversal (sec)
A	1.38	1.23
B	1.31	1.35
C	1.33	0.69

[1] Temporary Technical Provisions for Building in Seismic Regions, Official Gazette of S.F.R. Yugoslavia, No. 39/64

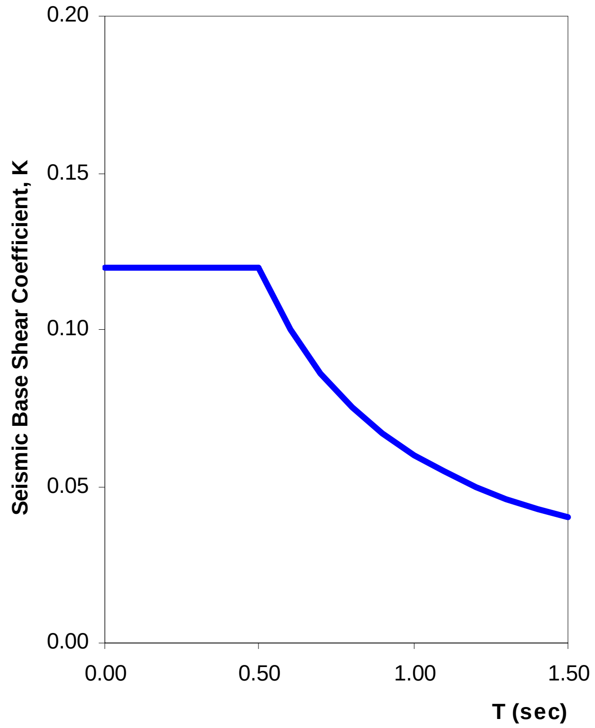


Fig. 2.2 Seismic Design Spectra of the Paediatric clinic (ref. [2])

2.3 Present state of the facility and maintenance

The building of the Paediatric clinic was constructed more than 20 years ago. General data about the state of the building of the Paediatric clinic and the level of maintenance were obtained by visual screening of exterior and interior of the facility.

In the basement, that hosts mainly the utilities, there were some problems with underground water from the very beginning of the exploitation which is evident from the state of the walls (Appendix B). At present, problems with water in the basement are resolved. There is a huge crack in one of the RC beams (Appendix B), part of the load bearing structural system, that has had appeared soon after completion of the structure. There are some additional significant cracks in the basement walls.

On other floors, except for a significant crack on the staircase shell wall (between 6th and 7th floor, (Appendix B), there are some occasional cracks on partition walls.

Some parts of the suspended ceiling are damaged and ruined, and this repeats on other floors also (Appendix B). Suspended ceiling partial demolition is a result of problems with the waste water piping that runs on the ceiling. Waste water piping needs reconstruction.

In total there are five elevators, four of them located in the central part of the structure, and one that is used for transportation of food from the kitchen to different floors. Only two of the elevators are in working condition (one for transportation of people and materials and the kitchen elevator), others are being repaired.

The pipelines and ducts throughout the building (water supply, electrical supply, heating, medical gases, etc.) are maintained by the technical staff employed at the Paediatric clinic and are in a good operating condition, except for the waste water piping.

The clinical laboratory is placed on the 7^{th} floor. The equipment that is located in the laboratory is not secured in any way in case the building is subjected to seismic motion. Chemical materials that are present in the laboratory are also stored without any precautions regarding a case of an earthquake.

Overall maintenance of the building is good.

2.4 Site geological conditions

The Paediatric Clinic is situated at the edge of the Clinical Centre Skopje (CCS), in the foothills of Mt. Vodno (Fig. 2.1). The geotechnical conditions of the site of CCS were defined using the data from the extensive geologic, hydrologic, geophysics, seismologic and tectonic investigations of the Skopje valley performed after the 1963 Skopje earthquake, as well as data accumulated during the reconstruction and construction activities at the CCS site and its surrounding.

The CCS is located on shallow gravel deposit (5–10 m) overlaying a marl base (Fig. 2.3) [8]. Throughout the location there is a covered fault that was defined by means of geologic investigations. The prevailing geologic materials that compose the soil profile (clay, sand and gravel over marl base) are defined based on data from two boreholes drilled within the location.

The location of the Paediatric Clinic in the foothills of the mountain is considered very unfavourable from the seismic point of view, since it is characterized with unconsolidated sediments created by the erosion of material from the mountain slopes. Also, the whole vicinity of the foothills is characterized with presence of underground waters. The empirical data on damages caused by earthquakes on such locations, from various authors, show that the experienced seismic intensity in such cases can be significantly greater than on sites with more favourable soil conditions, depending on the type of the soil and presence of the underground waters.

The experience points out that even moderate earthquakes can cause a substantial damage to structures that are placed on locations where the increase of the seismic intensity degree is possible. As for the location of the Clinical Centre, Skopje, due to the unfavourable characteristics of the site in terms of spatial location (foothills) and soil layers (sand, gravel) as well as presence of underground water, manifestation of higher seismic intensities can be expected when the location is exposed to earthquakes, especially to earthquakes from local or close seismic sources.

2.5 Site seismicity

The Skopje valley is a young depression edged with mountain massifs of Kitka, Osoj and Vodno from the south, Zeden from the west and Skopska Crna Gora from the north-east. It is neogene-quaternary depression that lies on the elongation of the directions of the structures of pelagoinian massif, close to the line north west - south east (Fig. 2.4) [8]. The collision of those two great tectonic units under the neogene complex of the valley and crossing of their approximate breaks, along with the tendency of differential movements of earth crust along them, determines the epicentral character of the Skopje valley.

Prior to 1900, the seismic history of Skopje, as part of the Vardar seismic zone, is practically reduced to a rather brief description of the earthquake catastrophes of Scupi in 518 AD and that of Skopje in 1555.

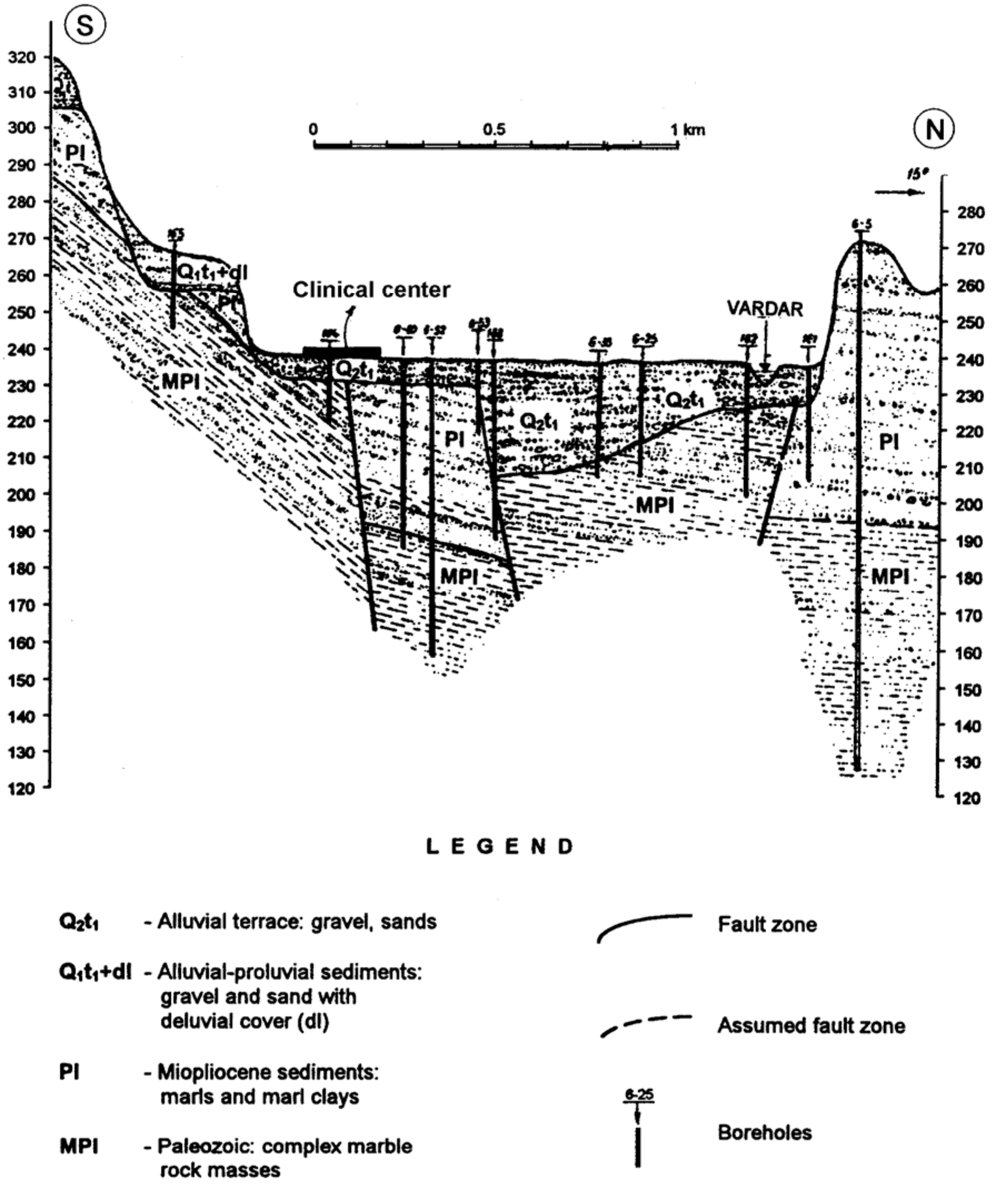


Fig. 2.3 N-S Geological profile of the right bank of river Vardar through CCS (ref. [8])

The old Scupi was situated about 4–5 km northwest of the centre of the present Skopje. As ground fissures extending over 45 km in length and up to 4 meters in width are reported for this earthquake, it seems that it is the strongest shock that has ever occurred in Macedonia. The earthquake of 1555 is said to have demolished a part of Skopje. Both earthquakes are estimated to be of an intensity of XII MCS (catalogues of the Seismological Institute of Belgrade). However, it is believed that the reported values are certainly overestimated.

During this century (Table 2.2) [8], the region of Skopje was affected by a series of damaging earthquakes, centred at the village of Mirkovci ($42^0$06'N, $21^0$24'E), which lasted from August to September 1921 with a magnitude of 4.6 to 5.1 and intensity of I = VII-VIII degrees MCS scale. Besides the local earthquakes, the region of Skopje has suffered several times from relatively distant earthquakes, e.g., from the Urosevac-Gnjilane region in southern Serbia, like in 1921.

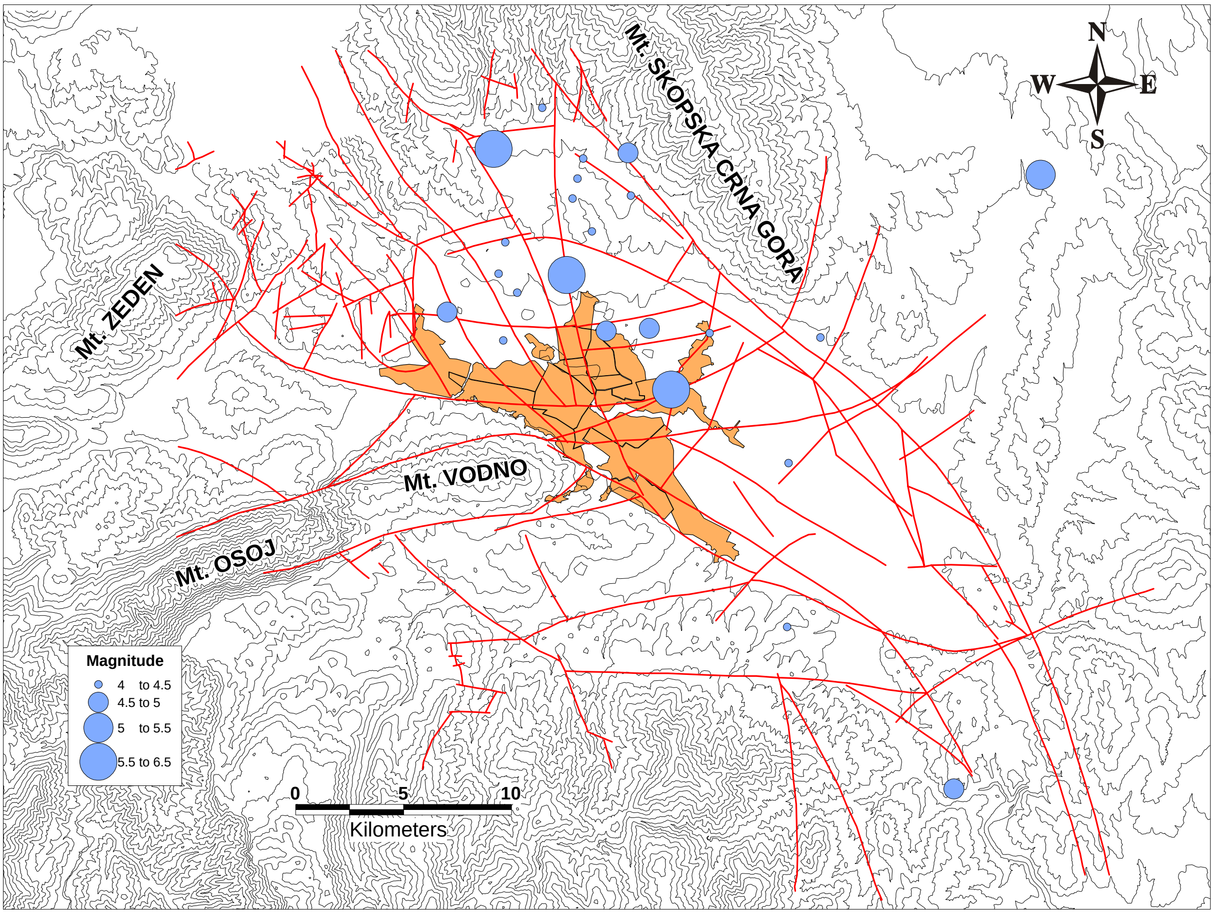


Fig. 2.4 Seismotectonic Map of the Greater Skopje Region

In the 1963 earthquake (M=6.1, I=IX-X MCS) the City of Skopje was devastated. About 77.4% of total building area (including dwelling houses) was destroyed or heavily damaged and 75.5% of inhabitants were left homeless. The direct economic losses were estimated at 1 billion 1963 US$, or at 15% of the GNP of former Yugoslavia for the year of 1963.

Table 2.2 List of the Strongest Earthquakes Affected Skopje in This Century

Earthquake	Year	M	I_0 (MCS)	Δ (km)	I_{SK} (MCS)
1. Pehcevo-Kresna	1904	7.8	X	125	VII
2. Urosevac-Vitina	1921	6.1	IX	40	VI
3. Valandovo	1931	6.7	X	115	VI
4. Tetovo-Gostivar	1960	5.6	IX	40	VI
5. Skopje	1963	6.1	IX	5–15	VIII-IX
6. Debar	1967	6.4	IX	115	V
7. Vrancea (Romania)	1977	7.2	IX	600	V
8. Montenegro (SR Yugoslavia)	1979	7.0	IX	190	V-VI

I_0 - Epicentral intensity; I_{SK} - Intensity in Skopje; Δ - Epicentral distance

Seismicity of the location of Clinical Centre Skopje is mainly determined by the seismicity of the Skopje valley associated with contemporary tectonic processes that caused strong to catastrophic earthquakes in the past. Maximum expected magnitude is M=6.5. The seismicity of the Skopje valley is dominantly controlled by the seismic activity of the local seismic sources. However, the seismicity of more distant seismic sources in Macedonia and wider Balkan region, that can generate magnitudes in the range from 6.5 to 8.0 is also contributing to the overall seismic exposure of Skopje region. The maximum expected seismic intensity is

IX (EMS-98), defined using the data from all earthquakes that had affected the region. It is unlikely, that the seismic intensity would exceed this value, but due to unfavourable soil conditions at particular microlocations within the urban zone, higher intensities might be manifested locally.

3. Seismic vulnerability evaluation of paediatric clinic

3.1 General

The seismic vulnerability evaluation of the Paediatric Clinic is performed using the **H**ealth facility integrated **V**ulnerability **E**valuation method (hereafter noted as HVE method) (Fig. 3.1) [15].

The method itself is suitable for preliminary (qualitative/quantitative) vulnerability assessment, identifying the possible weak elements in the facility and main vulnerability agents as well as deciding for prioritizations of the necessary further “in-depth” investigations.

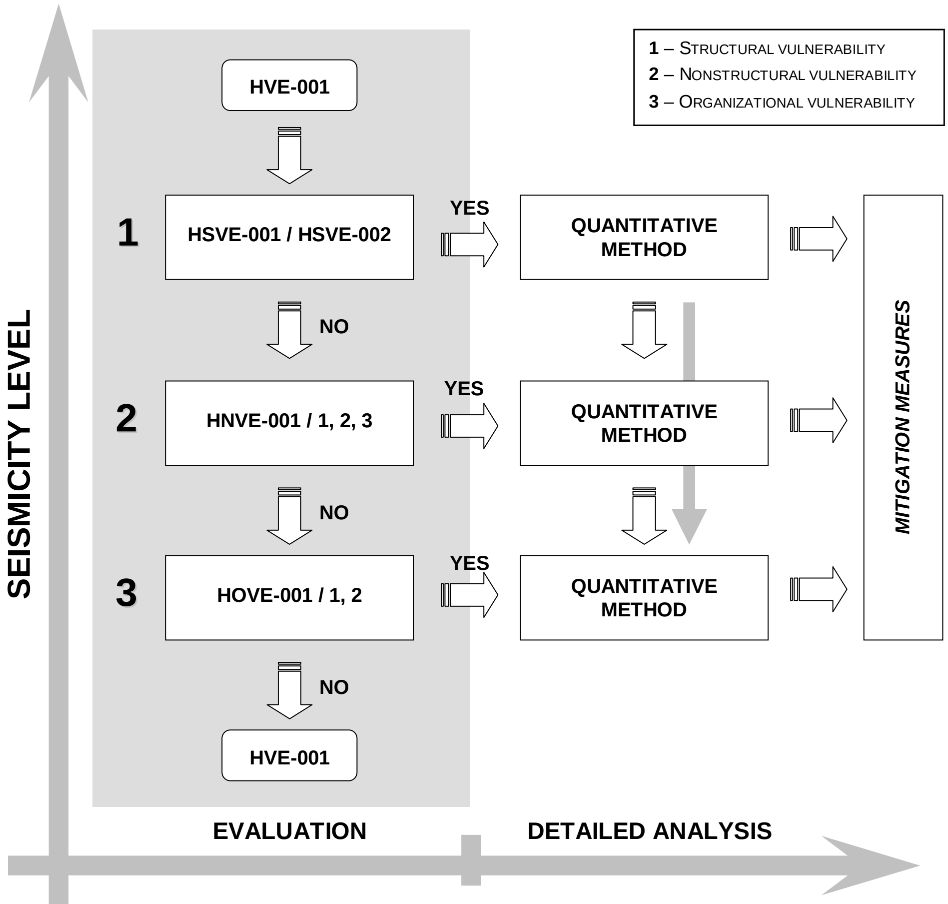


Fig. 3.1 Structure of the HVE method (ref: [15])

The HVE method is a hybrid method positioned mainly in the group of qualitative methods /rapid visual screening (RVS)/ combined with the screener's judgment. It connects separate evaluation methods for the three main vulnerability categories.

The RVS is performed by "sidewalk” survey of a building using the following data collection forms:

- HVE-001 form applicable to health facility general evaluation;
- HSVE-002 forms applicable to structural vulnerability evaluation;

- HNVE-001/1, HNVE-001/2 and HNVE-001/3 forms applicable to non-structural vulnerability evaluation; and,
- HOVE-001/1 and HOVE-001/2 forms applicable to A/O vulnerability evaluation.

The collected data are processed and corresponding vulnerability indices, risk ratings or screener judgments are calculated/assigned in order to evaluate facility: 1) structural; 2) non-structural; and, 3) administrative/organizational (A/O) vulnerability/performance.

For Paediatric clinic the following pre-RVS activities are completed and data compiled:

1. Selection and review of the data collection and evaluation forms
2. Determination of the site seismicity
3. Information on the local ground conditions
4. Review of the design and construction documents
5. Information on the level of seismic preparedness.

3.2 Structural vulnerability evaluation

The structural vulnerability evaluation of the Paediatric Clinic is performed by the form HSVE-002 (Appendix C) using vulnerability indices calibrated to Macedonian construction practice [14].

The structural type of the building is mixed: reinforced concrete frames (RC1) and reinforced concrete shear walls (RC2), however as a representative for vulnerability assessment the weaker one is considered [15]. Consequently the basic vulnerability index (V_I) is 31.

The building is designed according to 1964 Code and the second group of the vulnerability modifiers (V_m) is considered (period 1960–1980).

The code level and state of maintenance (good) does not contribute to the vulnerability level. The number of stories 8+ (basement+GF+7 stories) increase the vulnerability level for 3 scores. There is no significant plan or vertical irregularity that can increase the vulnerability of the facility including soft story or short columns.

The type of foundations is solitaire footings and the vulnerability modifier is 0.

According to the available geological data, the soil conditions at the Paediatric clinic site are estimated as medium (EC-8 classification) [3]. The vulnerability modifier for such soil conditions is 0.

The site seismicity is EMS-98 intensity IX^o.

The total vulnerability index (TV_I) is calculated as follows:

$$TV_I = V_I + \sum V_m$$

For the Paediatric clinic its value is 34 and the vulnerability level is estimated as moderate. Consequently, following the HVE criteria, a detailed structural vulnerability assessment is obligatory due to estimated level of structural vulnerability.

3.3 Non-structural vulnerability evaluation

The non-structural vulnerability evaluation of the Paediatric Clinic is performed using the forms (Appendix C) [15]: 1) HNVE-001/1 to evaluate architectural elements; 2) HNVE-001/2 to evaluate equipment and furnishings; and 3) HNVE-001/3 to evaluate basic installations and services.

The seismic exposure is estimated as high considering the site seismicity.

The non-structural vulnerability potential in the Paediatric clinic is described bellow.

3.3.1 Architectural elements

Architectural elements that contribute to the non-structural vulnerability of the Paediatric clinic are:

- ✓ Divisions and partitions – made of *hollow bricks* in case of infill walls or *glass* in order to facilitate surveillance of patients are considered as hazardous in case of an earthquake.
- ✓ Interiors – the design concept adopted for the paediatric clinic is very clean and functional, striped off all unnecessary architectural details, thus making the space less vulnerable.
- ✓ Ceilings – suspended ceiling dominates in the whole building, and might be a problem in case of an earthquake.
- ✓ Lighting – is incorporated into the suspended ceiling, thus posing a threat in case of an earthquake.
- ✓ Glass – is the most common hazard throughout the Paediatric clinic as it is present as large windows or as material for various partitions and divisions of the inner space of the building.

3.3.2 Equipment and furnishing

- ✓ Medical equipment present is not secured in a way that would prevent its movement (sliding/overthrowing) in case of an earthquake.
- ✓ Office equipment is not additionally secured.
- ✓ Furnishing – patient rooms are furnished only with essential furniture; there are no tall slender elements that can be overthrown; there are no objects hanging on the walls.
- ✓ Supplies (medical) are allocated at each department and can sustain approximately seven days of normal operation.
- ✓ Clinical files – each department keeps the files of the current patients; older files are kept in the common archive that is located in the basement of the building.

3.3.3 Basic installation and services

- ✓ Medical gases are distributed from the Clinical Centre central unit through a pipeline system.
- ✓ Electricity is supplied through the public utility; there is a diesel aggregate as a back up system that can amend 50% of the electrical power needed, for approximately 10 hours; there are additional back up accumulators for the equipment in the neonatology and intensive care departments.
- ✓ Telecommunications – there is no alternative to telephones.

- ✓ Plumbing system – there is no alternative water supply system; plumbing is maintained regularly and is in good condition.
- ✓ Existing operational fire detectors; existing operational internal and external fire suppression water supply system; existing operational fire extinguishers.

It should be noted that the medical gases supply system, plumbing and electric power supply system are maintained by the technical staff employed at the clinic. The maintenance and overall condition of these systems are considered good.

The total property loss and loss of function of different non-structural elements in Paediatric Clinic evaluated by the forms HNVE-001/1,2,3 (Appendix B) are presented in 3.1.

Table 3.1 Total property loss and loss of function of the Paediatric clinic

Non-structural element	Total property loss	Total loss of function
Architectural elements	High	Moderate
Equipment and furnishings	High	High
Basic installations and services	Moderate	High

3.4 Administrative/organizational vulnerability evaluation

Administrative and spatial organization of the Paediatric clinic which is very complex health facility, provides environment for performing diverse functions such as:

- outpatient-related functions
- diagnostic and treatment functions
- administrative functions
- service functions (food, supply).

These various functions are closely interrelated and interconnected defining the organization of the health facility.

The administrative/organizational (A/O) vulnerability evaluation was performed using the HOVE-001/1, 2 form (Appendix C) that consists of three parts [15]:

- Capability assessment
- Spatial distribution of services
- External interdependence (lifelines).

Data were obtained through screening of the hospital building and interview with the hospital officials.

3.4.1 Capability assessment

Capability assessment considers the assessment of personnel and resources allocation to various medical services existing at the health facility. Four parameters define the capability of each noted medical service:

- assigned personnel
- emergency supplies
- medical equipment
- backup systems.

According to the information obtained from the hospital officials, the number of emloyed personnel is adequate, although not optimal (75 doctors/191 other medical staff). The same can be stated for varios hospital departments/function, where the number of assigned personnel is also considered ***adequate*** *but not optimal*. The Paediatric clinic has on the average 250 patients daily, 20–25 are accepted for hospital treatment. Operating capacity is 230 inpatients, but in a case of need, *capacity can be expanded up to 10–15%.*

The Paediatric clinic is organized in several departments according to medical conditions that are treated, so the medical supplies needed for normal or emergency operation are defined and stored localy at each department. On average the existing medical supplies are sufficient for ***one week normal operation*** which can be defined as ***adequate***.

The medical equipment is distributed throughout hospitals' departments depending on the medical conditions that are treated and services they provide. The overall estimation of the equipment allocation and sufficiency can be rated as ***adequate*** especially having in mind the overall economic situation in the country. Maintenance of the equipment can sometimes be a serious problem (lack of parts, expensive service for older equipment).

Back up systems can be rated ***adequate***, since beside the main power supply back up system that can provide electric power for the most important functions of the hospital up to 10 hours, the most critucal medical departments, neonatology and intensive care, have additional back up system (acumulators).

3.4.2 Spatial distribution of services

The building of the Paediatric clinic was designed according to the requirements defined by the intended function and as a result the spatial distribution and organization of various medical and support services is adequately optimized. Most of the spaces retained the function to which they were initially assigned in the design process.

Spatial distribution of hospital functions is such that the clinical functions that mainly deal with outpatient are concentrated in the ground floor (examination rooms, diagnostic imaging, administration related to outpatients, admission). The emergency and intensive unit care are also on the ground floor, meaning that they are easily accessible.

Non-medical services such as food supply and laundry are placed in the basement. Various hospital departments are located on floors 1–6, while the 7^{th} floor is reserved for laboratories and administration. The object as a whole has a central part designated to communication (elevators, stairs) from and to various departments that enables easy access to various parts of the hospital and the spatial distribution can be rates as ***good***.

The only noted problem is the location of the laboratory which is on the last (seventh) floor that in case of an earthquake is the most vulnerable part since it will experience the largest displacements that can seriously jeopardize the laboratory equipment and contents. Even in daily routine due to the very poor function of the elevators (out of four only one is in working condition presently) the position of the laboratory is very unfavourable.

Other noted problem is the absence of emergency stairs.

3.4.3 External dependences

The lifelines systems are essential for health facility function, especially in an emergency situation, when the uninterrupted function is of outmost importance.

Access to the hospital:	both vehicle and pedestrian access is poor, since the access road is congested with parked cars, there is no alternative pedestrian or vehicle access; overall rating – ***poor***.
Power supply:	regular/backup supply system; capacity of the backup system amends partial (50%) load of operation for up to 10 hours; critical medical functions have additional power back up; overall rating – ***good***.
Water supply:	only regular supply system from the community utility, no backup system; overall rating – ***poor***.
Communication:	internal and external communication is performed solely with telephones (stationary and mobile), there are no alternative communication lines (radio connection); overall rating – ***average***.

The heating of the facility is provided from the central heating station that is in the immediate vicinity of the clinic (10–15m distance), that can be regarded as an additional hazard to the Paediatric clinic.

Earthquake emergency plans, response training and drills do not exist in the Clinic. The emergency supplies exist.

3.5 Health facility general evaluation

The general evaluation of the Paediatric Clinic is performed using the HVE-001 form. It is organized into two main parts. The first part contains: 1) facility general data; and, 2) information regarding facility seismic exposure and preparedness (Appendix C).

Taking into account the level of structural, non-structural and A/O vulnerability, the facility performance is estimated as: 1) structural performance – average; 2) non-structural – poor; and, 3) organizational performance – average.

4. Seismic vulnerability assessment

Considering the evaluated moderate level of structural vulnerability of the Paediatric Clinic it is necessary to perform more detailed structural vulnerability analysis in order to assess the expected damages of the facility and its seismic performance.

The seismic vulnerability analysis includes implementation of analytical methods to estimate the seismic behaviour of the facility and corresponding level of vulnerability/functionality. It consists of the following phases:

- ✓ Seismic demand estimation;
- ✓ Ambient vibration measurements; and,
- ✓ Assessment of the expected facility damageability and performance.

4.1 Seismic demand estimation

The seismic demand estimation is very important step in vulnerability analysis and its main task is estimation of the possible seismic actions at the site of interest.

Considering the recent advances in vulnerability/fragility analysis the seismic demand estimation is directed towards calculation of site-specific seismic demand spectra mainly as a result of probabilistic seismic hazard analysis (PSHA).

In order to estimate the seismic demand for the Paediatric Clinic a method for computing hazard-consistent seismic demand (HCD) spectra is used [14]. The method itself is based on extended seismic hazard analysis performed in the following steps: 1) delineation of the seismic sources; 2) estimation of the seismic activity parameters through complex management of earthquake catalogue; 3) definition of hazard-consistent events using quadriparametric seismic hazard disaggeregation for predefined seismic hazard return periods; and 4) computing hazard-consistent spectra as an attenuation of the hazard-consistent magnitude and distance.

The hazard-consistent seismic response spectrum is defined as seismic response spectrum at certain location caused by the hazard-consistent earthquake. It refers to mean elastic acceleration spectrum $\overline{S}_{A,el}(T,p_o)$ [14].

$$\overline{S}_{A,el}(T,p_o) = f_T\left[\overline{M}(p_o), \overline{\Delta}(p_o) \mid \overline{T}(p_o)\right]$$

where f_T is attenuation of spectral accelerations, p_o is seismic hazard level.

$$\overline{S}_{D,el}(T,p_o) = \frac{\overline{S}_{A,el}(T,p_o)}{4\pi^2}T^2$$

$$\overline{S}_A(T,p_o) = \frac{\overline{S}_{A,el}(T,p_o)}{R_\mu} \qquad \overline{S}_D(T,p_o) = \frac{\overline{S}_{D,el}(T,p_o)}{R_\mu}\mu$$

where μ is ductility ratio and R_μ is the strength reduction factor.

Table 4.1 Seismic Hazard Return Periods

Earthquake	**Return period (yrs)**	**Probability of exceedance p_o (%)**
Frequent	43	50% in 30 yrs
Occasional	72	50% in 50 yrs
Rear	475	10% in 50 yrs
Very rear	970	10% in 100 yrs

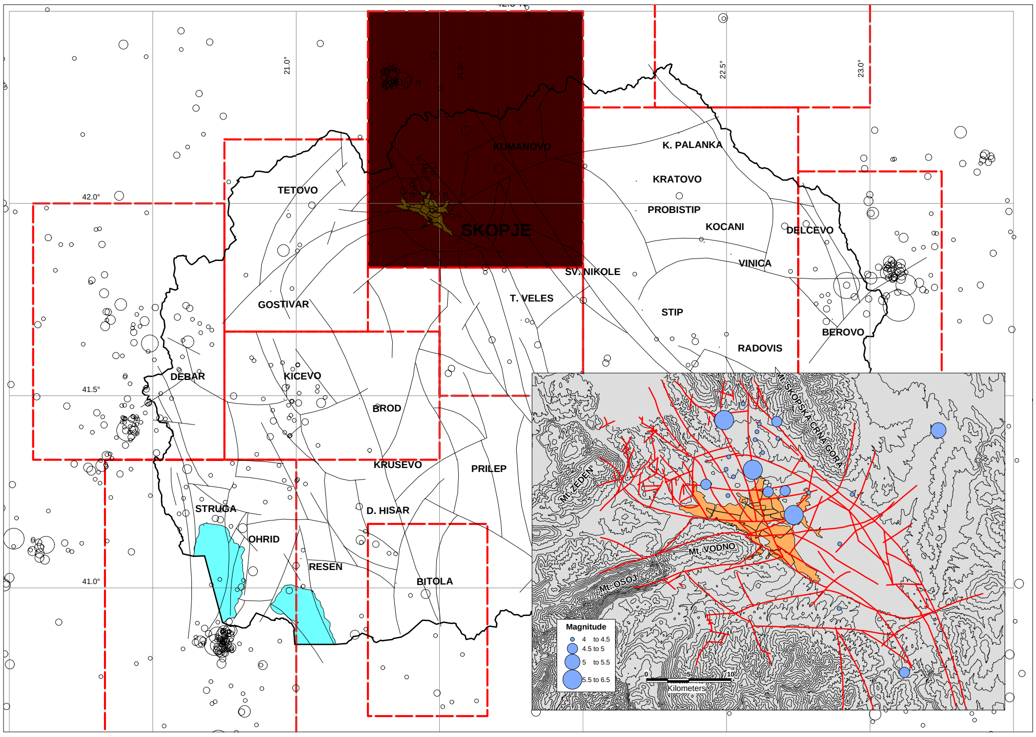


Fig. 4.1 Local Seismic Source Skopje-Vitina (ref: [14])

The quadriparametric disaggregation of the seismic hazard is performed using the Ambraseys, 1996 spectral acceleration attenuation relationship (medium soil conditions) as well as the Seed and Idriss, 1975 predominant period attenuation relationship.

The HCD spectra for the City of Skopje for return periods of 43, 72, 475, 970 years and ductility demand μ=4 are presented in Fig 4.2.

These spectra are adopted as seismic demand for the Paediatric Clinic.

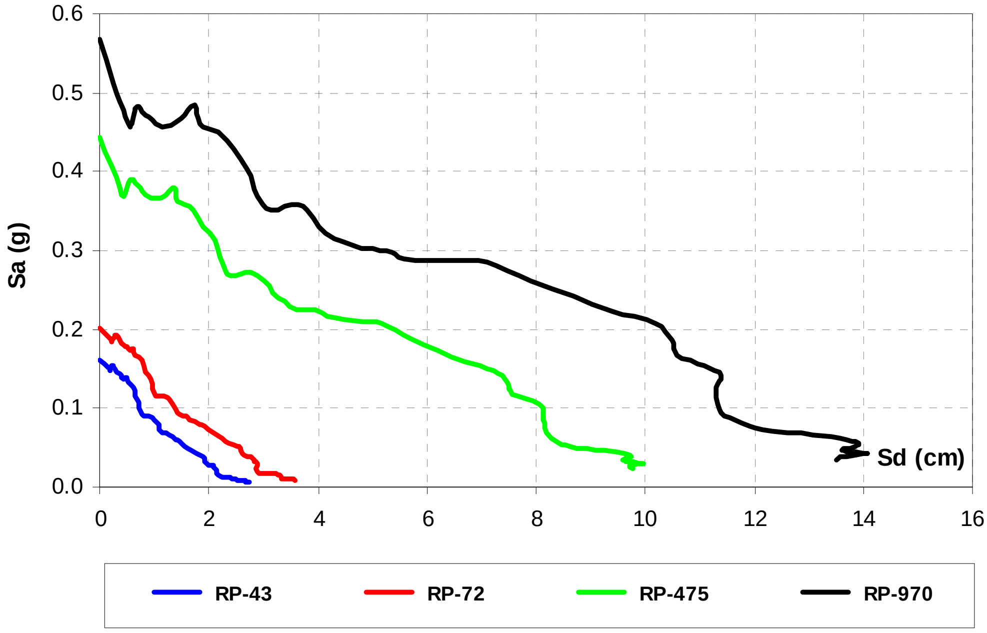


Fig. 4.2 HCD Spectra for the Paediatric clinic

4.2 Ambient vibration measurements

For seismic response assessment of a structure the real dynamic characteristic of the building are required. In order to estimate and validate the building predominant elastic period of vibration, ambient vibration measurements are performed in various places of the Paediatric Clinic such as:

- ✓ Block A – 8 measuring points (basement, ground floor, second to seventh floor)
- ✓ Block B – 4 measuring points; (basement, second, third and seventh floor)
- ✓ Block C – 3 measuring points (basement, ground and seventh floor).

In total, 30 measurements have been completed (15 points x bidirectional measurements - longitudinal and transversal direction). For the stated needs three Micromed s.r.l. TROMINO Portable Ultra-light Seismic Noise Acquisition Systems were used. The positions of the performed measurements are presented in Fig. 4.3.

The obtained records are processed on the entire trace using window size of 30 sec and Konno-Omachi smoothing algorithm with b-value = 20.

The representative Fourier amplitude spectra are presented in Fig. 4.4.

The building predominant period of vibration is always associated with the largest amplitudes in the spectra. Consequently, the predominant elastic periods of vibration in longitudinal and transversal directions of the Paediatric Clinic are estimated at 0.51 and 0.5 sec, respectively.

The performed measurements revealed the fact that the predominant periods of vibration in both directions are almost the same and that the choice of the measurement location does not affect the obtained results meaning that the building in elastic domain behaves as single unit regardless the expansion joints.

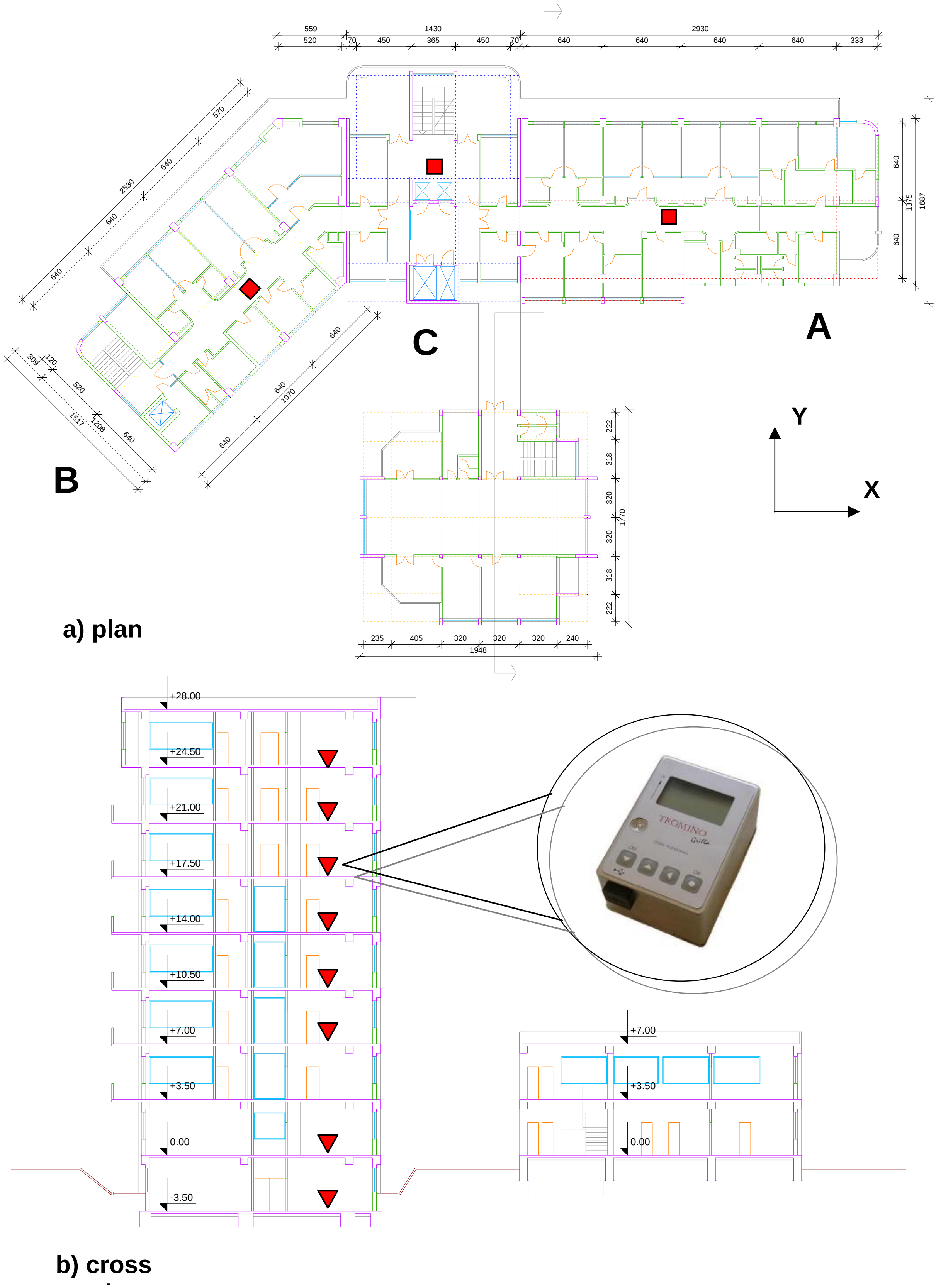
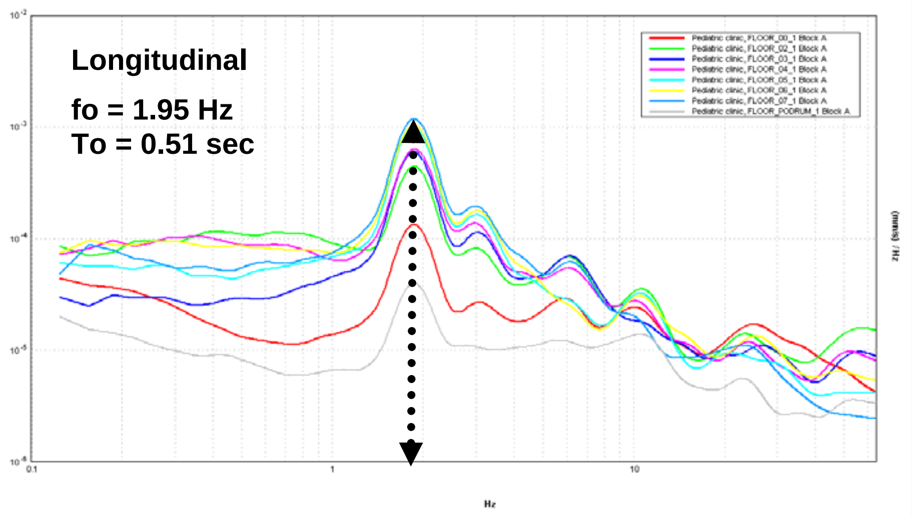
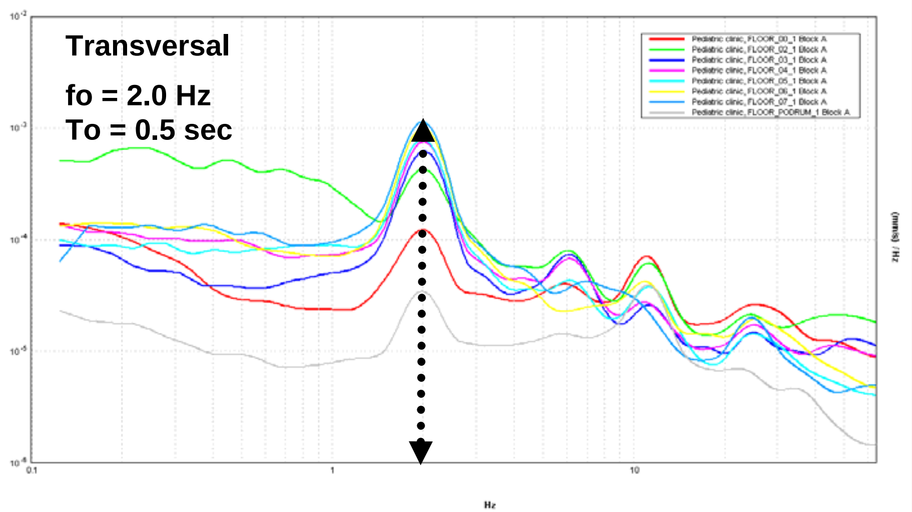


Fig. 4.3 Ambient vibration measuring points

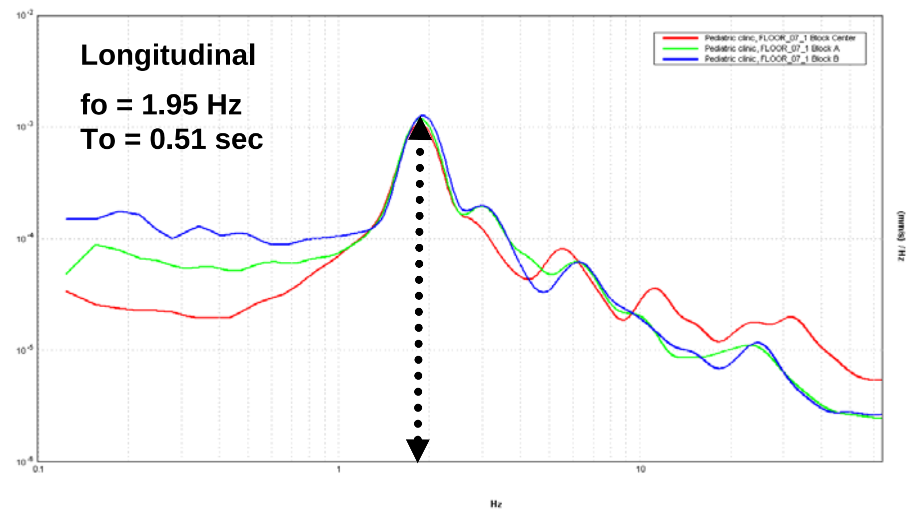
Fig. 4.4 Representative ambient vibration amplitude spectra of the Paediatric Clinic

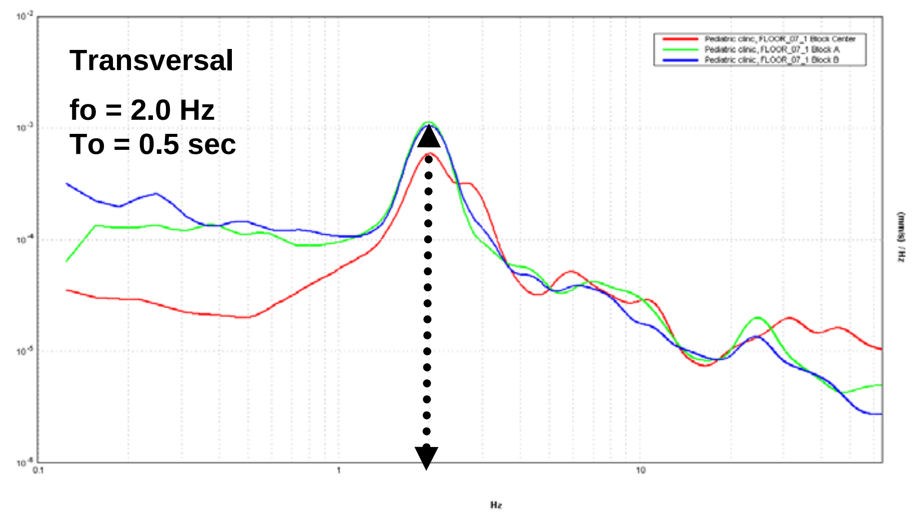
Block A – eight measuring points





Blocks A, B and C, measurements at seventh floor





4.3 Assessment of the expected facility damageability and performance

The structural vulnerability analysis was performed in the following steps [14]:

- ✓ Structural response estimation
- ✓ Developing fragility models
- ✓ Assessment of the expected damage grade and facility performance.

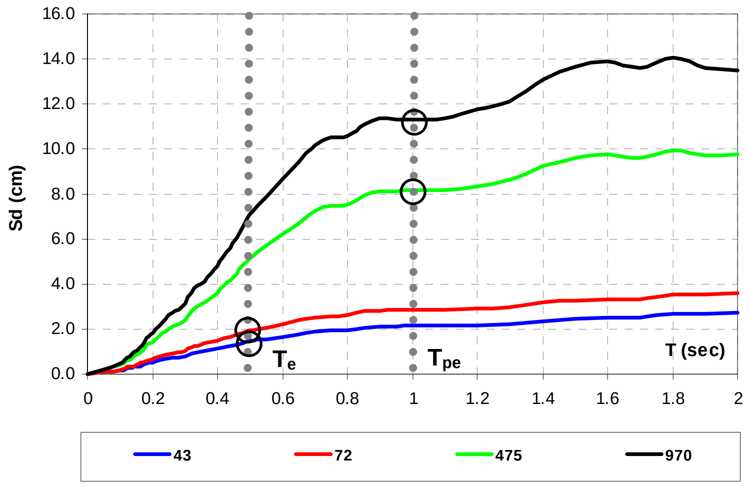
All analyses are performed for the Block A which is considered as the most vulnerable part of the facility.

The structural response is estimated using displacement coefficient (DC) method [5,14]. The method itself belongs to the group of simplified inelastic procedures that are the most rational analysis and performance evaluation methods for practical structural applications.

In DC method the structural response i.e. spectral displacement (inelastic hazard-consistent) is estimated in frequency domain as amplitude at building predominant period of vibration as follows:

$$S_{D,str} = \overline{S}_D(T_{str}, p_o) = \frac{\overline{S}_{D,el}(T_{str}, p_o)}{R_\mu}\mu$$

In calculation of the building seismic response, for return periods of 43 and 72 years, the building predominant elastic period of vibration (T_e) is used since it is considered that for such seismic demands the structure will experience elastic to slightly non-elastic behaviour For return periods of 475 and 970 years the post-elastic predominat period of vibration (T_{pe}) is used. It is calculated using the modal analysis by neglecting the contribution of the non-structural elements to overall structural stiffness since it is considered that the structure for such seismic demands will experience extensive non-structural damages (Fig. 4.5).

<table>
<tr><th>Spectral displacement</th><th>Structural response</th></tr>
<tr><td>
</td><td>

T_e = 0.5 sec

T_{pe} = 1.0 sec

$S_{d,43}$ = 1.5 cm

$S_{d,72}$ = 1.9 cm

$S_{d,475}$ = 8.1 cm

$S_{d,970}$ = 11.3 cm
</td></tr>
</table>

Fig. 4.5 Structural response of the Paediatric clinic for different SH return periods

The fragility models are developed using L2 fragility method [9, 14]. It is based on nonlinear dynamic analysis of structures and statistical data processing for the global damage index and the corresponding spectral displacement at the top of the building.

It uses:

- one-dimensional shear-type model for nonlinear dynamic analysis
- representative set of earthquakes for 25 acceleration levels (0.02–0.55 g)
- bilinear hysteretic model
- Park & Ang damage model.

Analytical fragility functions are modelled by cumulative lognormal distribution as follows

$$P[ds \mid S_d] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\overline{S}_{d,ds}}\right)\right]$$

where S_d is spectral displacement at the top of the building at which there is a conditional probability ***p*** of being in or exceeding the damage state ds; $\overline{S}_{d,ds}$ is the median value of the spectral displacement at the top of the building; β_{ds} - is a standard deviation of the natural logarithm of the spectral displacement for damage state ds; and Φ is the standard normal cumulative distribution.

The representative fragility models for the Paediatric Clinic are presented in Fig. 4.6.

The probabilities for reaching certain damage state (none, slight, moderate, extensive and collapse) are estimated using the Paediatric clinic fragility models (Fig. 4.7).

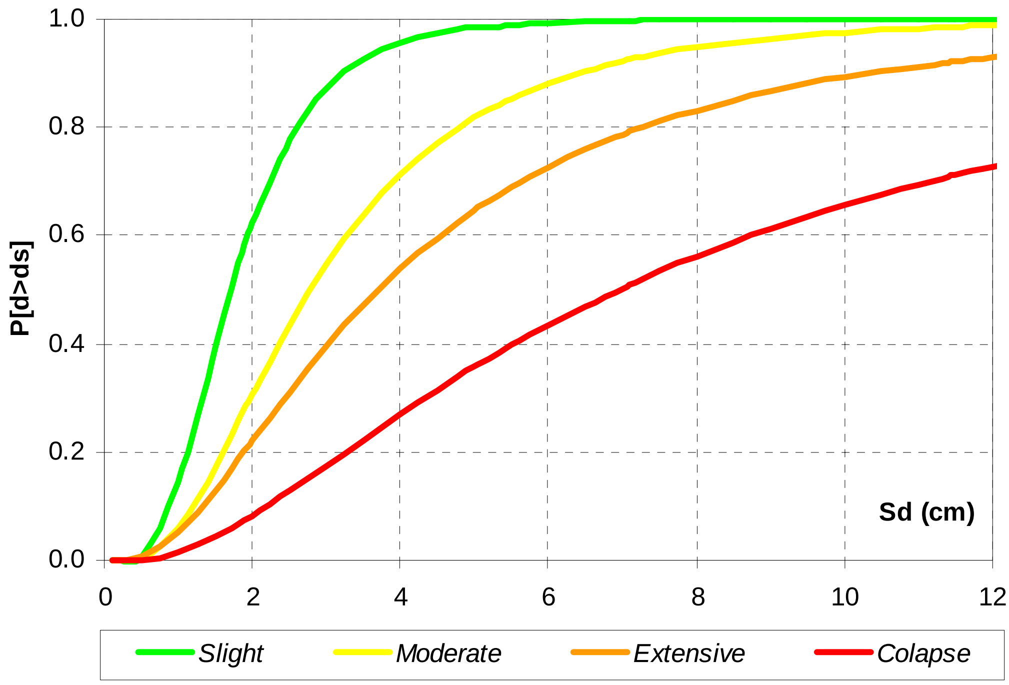


Fig. 4.6 Fragility models for Paediatric Clinic

The expected damage grades for the Paediatric clinic for different SH return periods are: RP-43 **1**, RP-72 **1**, RP-475 **3** and RP-970 **3-4**.

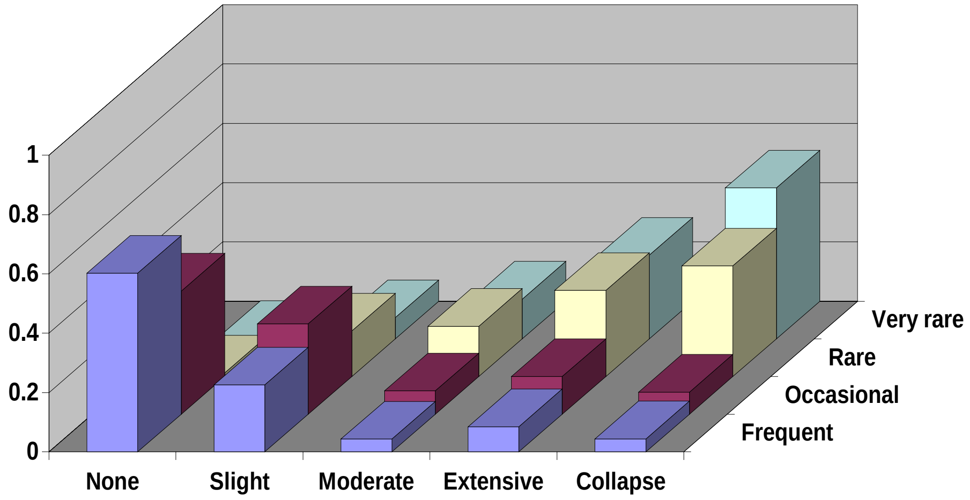


Fig. 4.7 Damage Probabilities for the Paediatric clinic

The analyses revealed the fact that for frequent and occasional near-field earthquakes the building might experience negligible to slight damages described as follows:

Negligible damages — Without visible damage to structural elements. Possible fine cracks in the wall and ceiling mortar. Hardly visible non-structural and structural damage.

Slight damages — Cracks to the wall and ceiling mortar. Falling of patches of mortar from wall and ceiling surface. Considerable cracks, or partial failure of chimneys, attics and gable walls. Disturbance partial sliding, sliding and falling down of roof covering. Possible cracks in structural elements.

Unanchored medical equipment and furnishings including the glass partitions might experience moderate to extensive damages even for frequent and occasional earthquakes.

For rare and very rare near-field earthquakes the building might experience heavy damages described as follows:

Heavy damages — Large cracks with or without disattachment of walls with crushing of materials. Large cracks with crushed material of walls between windows and similar elements of structural walls. Large cracks with small dislocation of RC structural elements: columns, beams, RC walls. Slight dislocation of structural elements and the whole building.

For rare and very rear earthquakes the non-structural damages might be to extent of complete loss of facility function.

The compliance with the design criteria and seismic performance of the Paediatric clinic is checked against: 1) 1964 Code; 2) 1981 Code[2]; and, 3) Vision 2000 performance objectives matrix (Fig. 4.8) [1].

2 Code of Technical Regulations for the Design and Construction of Buildings in Seismic Regions, Official Gazette of S.F.R. Yugoslavia, No. 31/81, 49/82, 29/83, 21/88, 52/90

The Paediatric clinic is designed according to 1964 Code and the review of the existing design documents and plans revealed the fact the code was strictly followed.

Considering the criteria prescribed by the 1981 Code (still in effect in Republic of Macedonia) according to which the structure for rare earthquakes can experience any type of damage but collapse, it can be concluded that expected seismic performance of the Paediatric clinic comply with the actual aseismic design code.

However, considering the latest trends in earthquake engineering in view of the performance based design of structures (SEAOC Vision 2000), the criteria become more rigorous taking into account the facility functionality as well. They prescribe essential/hazardous objectives as minimum acceptable requirements for essential facilities which are critical to post earthquake operations such as hospitals, police stations, fire stations, communication centres, emergency control centres, and shelters for emergency response vehicles.

Consequently, the Paediatric Clinic facility should be: 1) fully operational for frequent and occasional earthquakes; 2) operational for rare earthquakes; and 3) life-safe for very rare earthquakes.

Seismic Level	Required performance level			
	Fully functional	Operational	Life safety	Near collapse
Frequent (50%/30 years)	✖		**Unacceptable performance** (For new buildings)	
Occasional (50%/50 years)	◆	✖		
Rare (10%/50 years)	■	◆	✖	
Very rare (10%/100 years)		■	◆	✖

🖶 Basic objectives; ❶ Essential/hazardous objectives; ⑤ Safety critical objectives

Fig. 4.8 Seismic performance objective matrix (ref: [1])

The fully functional level corresponds to damage grade 1, operational to damage grade 2, life safety to damage grade 3 and near collapse to damage grade 4.

Considering the expected damage grades for different seismic levels it can be concluded that the Paediatric Clinic has satisfactory performance for frequent and occasional earthquakes. For rare and very rare earthquakes the Clinic is not satisfying the prescribed performance targets.

The estimated unacceptable level of damageability and seismic performance of the Paediatric clinic for seismic demand for rear and very rare earthquakes is mainly due to the low ductility demands in the design criteria prescribed by the 1964 Code.

4.4 Seismic vulnerability mitigation measures for the Paediatric clinic

From the performed analyses two scenarios might be distinguished for the Paediatric clinic: 1) Scenario 1 – frequent and occasional near-field earthquakes; and, 2) Scenario 2 – rare and very rare near-field earthquakes.

For each scenarios the following seismic mitigations measures for the Paediatric clinic are proposed:

Scenario 1

Structural vulnerability

No mitigation measures are required since only slight structural damages are expected.

Non-structural vulnerability

The proposed non-structural mitigation measures for the existing hazards in the Paediatric clinic are presented in Table 4.2 [4,12].

For the other non-structural elements such as lifeline systems (plumbing, electricity, heating, medical gases) no particular mitigation measures are proposed since the design and regular maintenance is adequate and no significant damages and interruption are expected.

Organizational vulnerability

From the space distribution point of view, the Paediatric clinic is properly organized. The only noted problem is the location of the laboratory which is on the last (seventh) floor that in case of earthquake is the most vulnerable part since it will experience the largest displacements that can seriously jeopardize the laboratory equipment and contents. Dislocation of the laboratory should be considered.

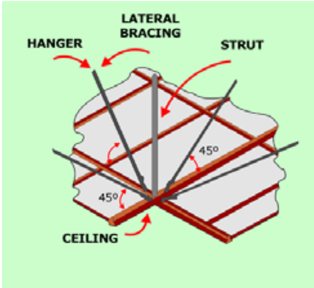
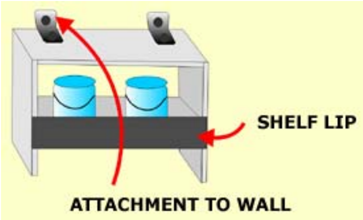
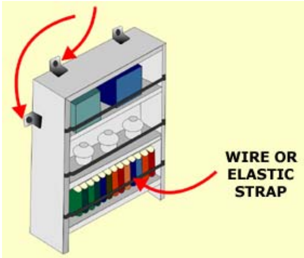
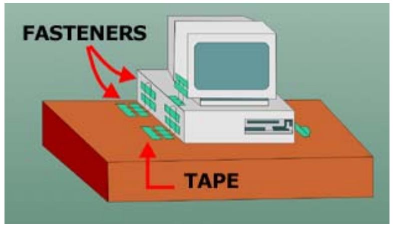
Elaboration of emergency response plans and training of the personnel is strongly recommended.

Scenario 2 (Rare and very rear earthquakes)

Structural vulnerability

For rare and very rare earthquakes the Paediatric clinic might experience unacceptable seismic performance. Consequently, more detailed analysis for the stated seismic demands and elaboration of retrofit project for Paediatric clinic is recommended. This will improve the seismic safety of the structure and will significantly improve the non-structural performance of facility.

Table 4.2 Non-structural mitigation measures (ref: [4,12])

Existing hazard	Mitigation measure	Photo
Glass (partitions, windows)	Utilization of safety glass (expensive option). Covering with plastic transparent foil in order to prevent glass shattering.	
Suspended Ceilings	Adequately mounted to floor structure with restrainers (lateral bracing).	
Lighting	Properly protected and mounted to ceilings.	
Unfastened cabinets and shelves	Cabinets and shelves properly secured to the wall using angle brackets in order to avoid dislocation or overturning. Free standing units fastened with continuous angles to floor. The overturning of existing items secured by means of secure lip, metal wire or elastic straps. Install mechanical drawer latches and mechanical cabinet catches.	 
Monitors, computers or similar equipment	To be fastened to table with adhesive tape or connecting straps.	

5. Conclusions and recommendations

The Paediatric Clinic is part of the University Hospital Campus that incorporates 25 Clinics (18 of the Clinical Centre, Skopje and 7 Clinics of the Stomatology Clinical Centre, Skopje). It is organized in several departments such as: intensive care, neonatology, pulmonology, neurology, psychiatry, immunology, oncology, etc. and provides high level professional health care for the patients from all parts of the country.

The Paediatric Clinic is situated at the edge of the Clinical Centre, in the foothills of Mt. Vodno. From seismic point of view its site is considered as very unfavourable, since it is characterized with unconsolidated sediments created by the erosion of material from the mountain slopes. Also, the whole vicinity of the foothills is characterized with presence of underground waters.

The site seismicity is mainly determined by the seismicity of the Skopje valley associated with contemporary tectonic processes that in the past caused strong to catastrophic earthquakes. Maximum expected magnitude is M=6.5. The seismicity of the Skopje valley is dominantly controlled by the seismic activity of the local seismic sources. However, the seismicity of more distant seismic sources in Macedonia and wider Balkan region, that can generate magnitudes in the range from 6.5 to 8.0 is also contributing to the overall seismic exposure of Skopje region. The maximum expected seismic intensity is IX (EMS-98). It is unlikely, that the seismic intensity would exceed this value, but due to unfavourable soil conditions at particular microlocations within the urban zone, higher intensities might be manifested locally.

The Paediatric Clinic was designed in 1979 by the Construction Company “Beton”. The construction of the building is completed in the period 1980–1984 and the building itself was put in effect in 1985. It is separated by expansion joints into three blocks. The main bearing system of the wing blocks are RC frames and RC shear walls in the central part.

Overall maintenance of the building is good.

The building was designed according to 1964 Code (Temporary Technical Provisions for Building in Seismic Regions, Official Gazette of S.F.R. Yugoslavia, No. 39/64) with “increased seismicity (IX+)” due to the importance of the facility and adopting good soil conditions. It should be mentioned that all the structures designed according to this “force-based” code possess very limited post-elastic ductility capacity without any consideration of the non-structural elements.

Seismic vulnerability assessment of the Paediatric clinic was performed taking into account the aforestated including its importance in the health-care system of the country and the occupancy type – very vulnerable part of the population: children of all ages, ranging from newborns to 14 years.

The seismic vulnerability evaluation including structural, non-structural and administrative/organizational vulnerability of the Paediatric Clinic is performed using the **H**ealth facility integrated **V**ulnerability **E**valuation method (hybrid RVS-based method).

The structural vulnerability is evaluated using vulnerability indices calibrated to Macedonian construction practice. As a representative for vulnerability assessment the load bearing system of the lateral wings is considered i.e. RC frames. Moderate level of structural vulnerability is evaluated for the Paediatric clinic.

The non-structural vulnerability i.e. the expected total property loss and loss of function of different non-structural elements (architectural elements, equipment and furnishings and basic installations and services) is evaluated as moderate to high.

The administrative/organizational vulnerability evaluation was based on the data obtained through screening of the hospital building and interview with the hospital officials. Three aspects were considered and evaluated: 1) facility capacity (adequate); 2) spatial distribution of the services (good); and, 3) external dependence (poor to good).

The overall facility performance is evaluated as: 1) structural performance – average; 2) non-structural – poor; and, 3) organizational performance – average.

Due to the evaluated level of structural vulnerability and according to HVE criteria structural vulnerability assessment is performed. It consists of the following phases: 1) Seismic demand estimation; 2) Ambient vibration measurements; and, 3) Assessment of the expected facility damageability and performance.

The seismic demand for the Paediatric Clinic is computed as hazard-consistent seismic demand (HCD) spectra for medium soil conditions and return periods defined with SEAOC Vision 2000 document (43, 73, 475 and 970 years).

The ambient vibrations measurements were performed at 15 measuring points (in total 30 bidirectional measurements, transversal and longitudinal) in order to estimate and validate the building predominant period of vibration. The performed measurements revealed the fact that the predominant elastic periods of vibration in both directions are almost the same (0.5 and 0.51 sec).

The structural seismic response of the Paediatric clinic is estimated using displacement coefficient method in frequency domain as amplitude at building's predominant period of vibration. In calculation of the building seismic response, for return periods of 43 and 72 years, the building predominant elastic period of vibration (T_e) is used since it is considered that for such seismic demands the structure will experience elastic to slightly non-elastic behaviour. For return periods of 475 and 970 years the post-elastic predominat period of vibration (T_{pe}) is used. It is calculated using the modal analysis neglecting the contribution of the non-structural elements to overall structural stiffness since it is considered that the structure for such seismic demands will experience extensive non-structural damages.

The expected spectral displacements for different SH return periods are as follows: $S_{d,43}$ = 1.5 cm, $S_{d,72}$ = 1.9 cm, $S_{d,475}$ = 8.1 cm and $S_{d,970}$ = 11.3 cm.

The vulnerability analysis distinguished two scenarios: 1) scenario 1 – frequent and occasional near-field earthquakes; and, 2) scenario 2 – rare and very rare near-field earthquakes.

For scenario 1 the building might experience negligible to slight damages (structural and architectural non-structural). Unanchored medical equipment and furnishings including the glass partitions might experience moderate to extensive damages.

For scenario 2 the building might experience heavy to very heavy structural damages. The non-structural damages might be to extent of complete loss of facility function.

The compliance with the design criteria and seismic performance of the Paediatric clinic is checked against: 1) 1964 Code; 2) 1981 Code; and, 3) Vision 2000 performance objectives matrix.

The Paediatric clinic is designed according to 1964 Code and the review of the design documents and plans revealed the fact the code was strictly followed.

Considering the criteria prescribed by the 1981 Code (still in effect in Republic of Macedonia) according to which the structure for rare earthquakes can experience any type of damage but collapse, it can be concluded that expected seismic performance of the Paediatric clinic comply with the actual aseismic design code.

According to Vision 2000 criteria the Paediatric Clinic has satisfactory performance for frequent and occasional near-field earthquakes, however, for rare and very rare near-field earthquakes the Clinic does not satisfy the prescribed performance targets. The estimated unacceptable level of damageability and seismic performance of the Paediatric clinic is mainly due to the low ductility demands in the design criteria prescribed by the 1964 Code.

The short-term mitigation measures mainly refer to scenario 1 demands.

It is recommended to perform non-structural mitigation program for some of the architectural elements such as: glass partitions, windows, suspended ceilings and lightning and unfastened furniture. For the other non-structural elements such as lifeline systems (plumbing, electricity, heating, medical gases) no particular mitigation measures are proposed since the design and regular maintenance is adequate and no significant damages and interruption are expected.

From organizational point of view, dislocation of the laboratory should be considered since it is placed at the top story where the largest displacements are expected and they can seriously jeopardize the laboratory equipment and contents and its overall functionality.

Elaboration of emergency response plans and training of the personnel for the Paediatric clinic is also strongly recommended.

The long-term mitigation measure refer to scenario 2 demands. In order to improve the seismic safety of the structure and the non-structural performance of facility it is recommended to complete more detailed vulnerability analysis of the structure (preferably nonlinear dynamic analysis with selected earthquake records) and to propose corresponding retrofit program.

6. References

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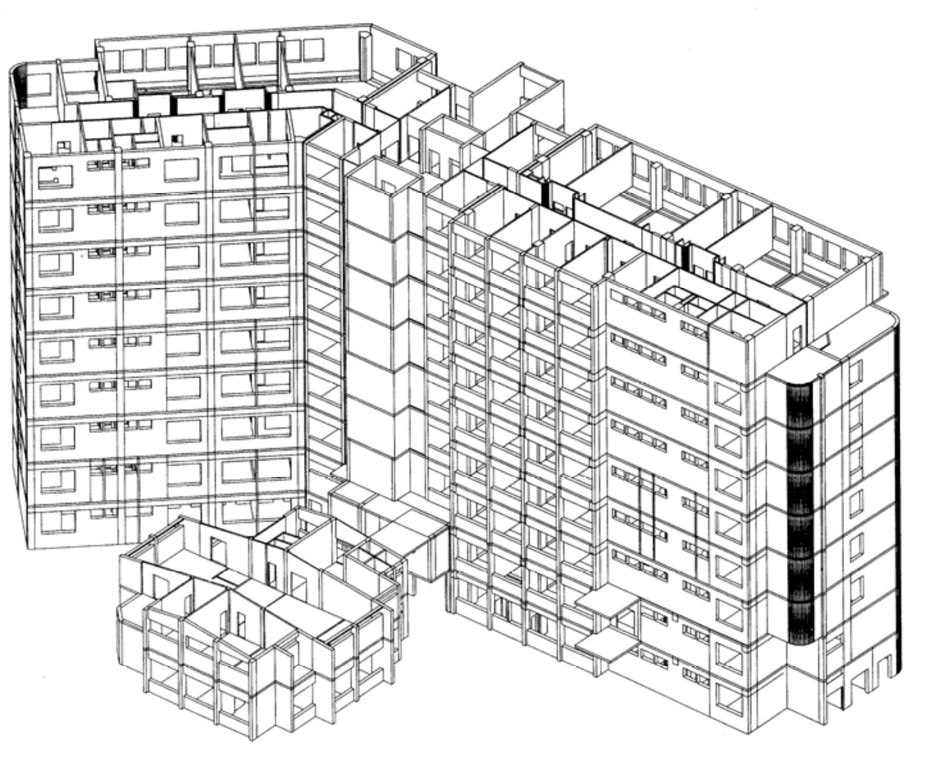
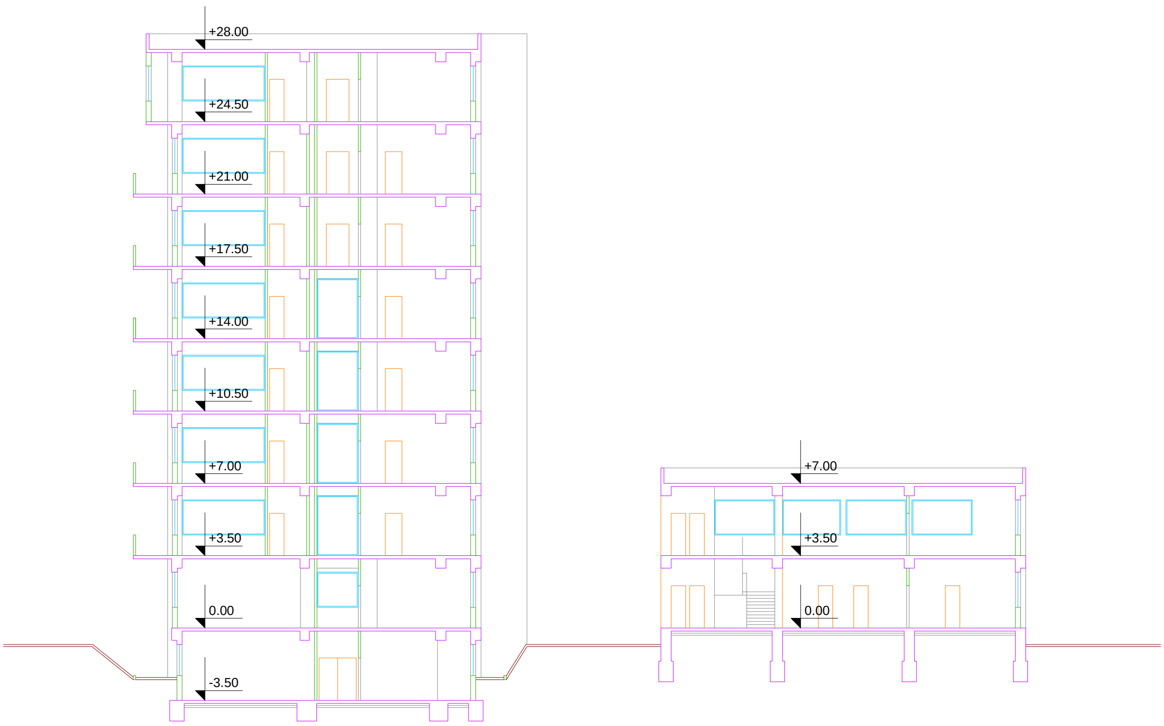
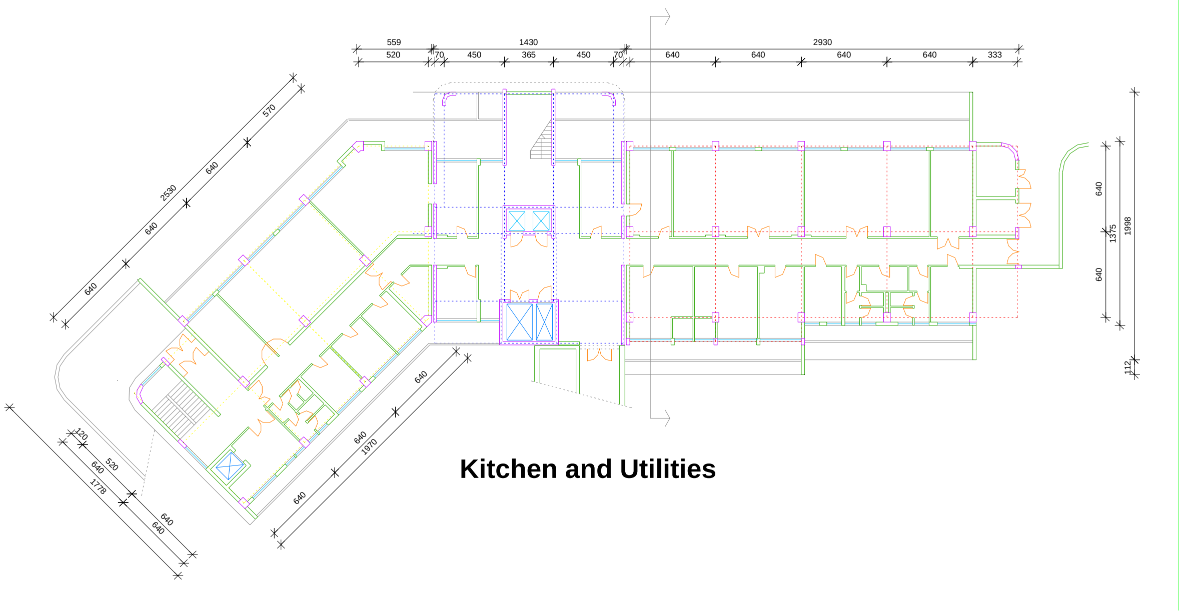
APPENDIX A: PLANS OF THE PAEDIATRIC CLINIC



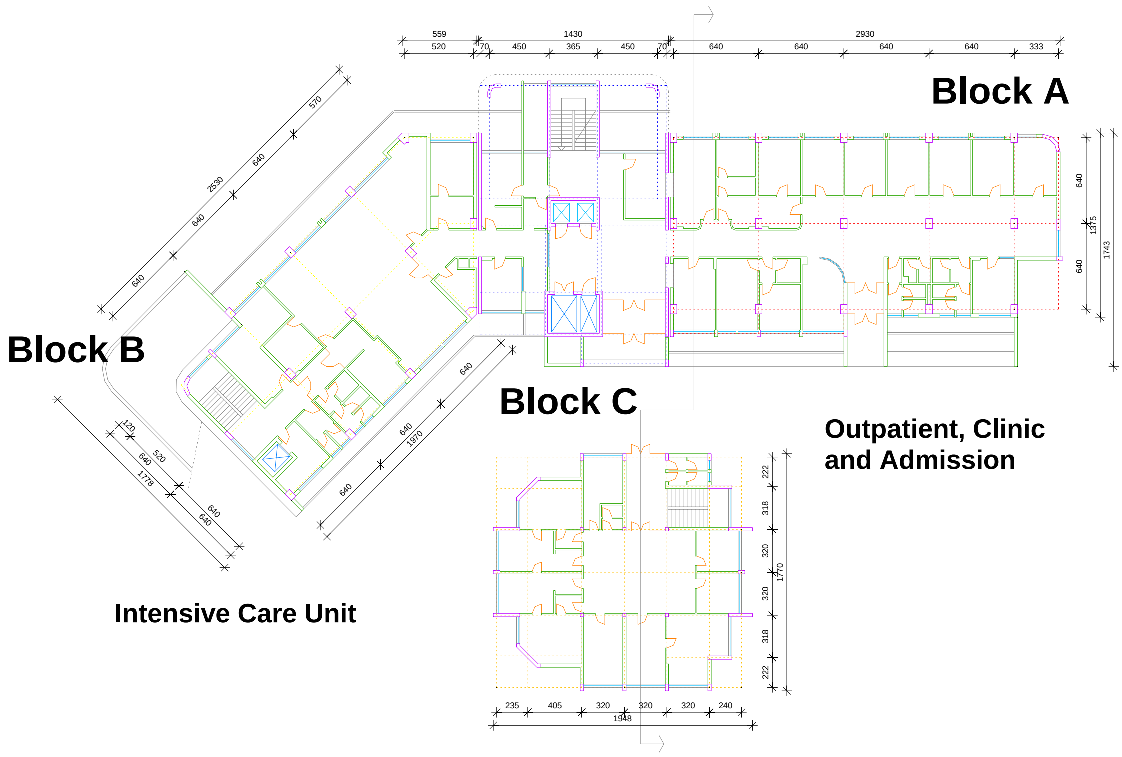
Axonometric view



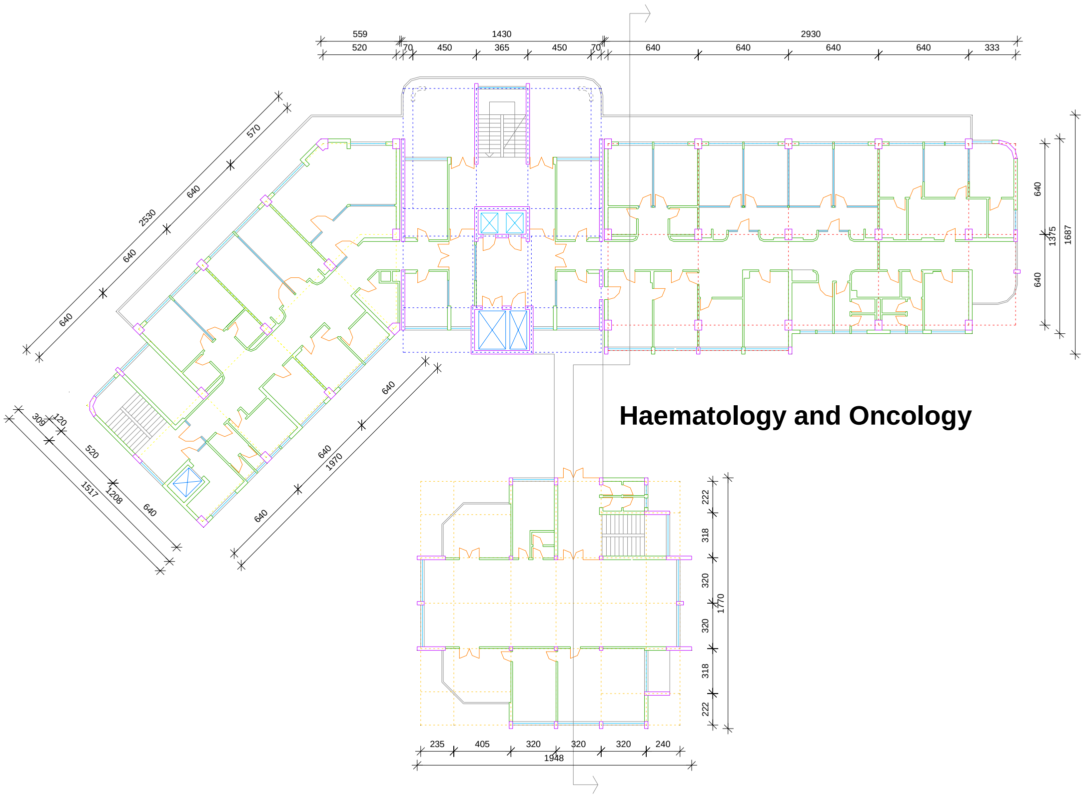
Cross Section



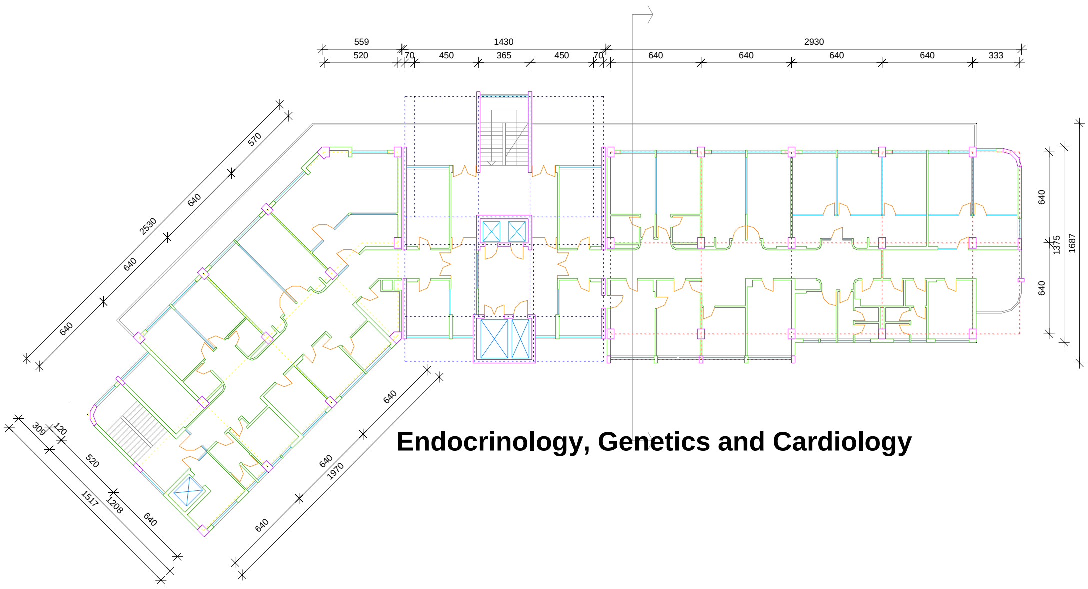
Basement



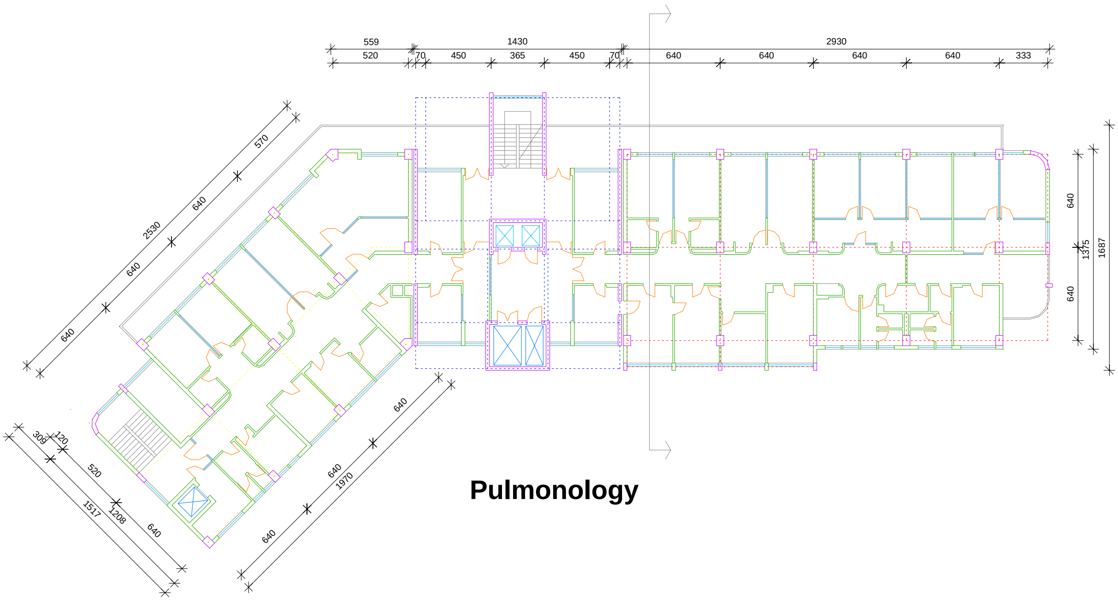
Ground floor



First floor

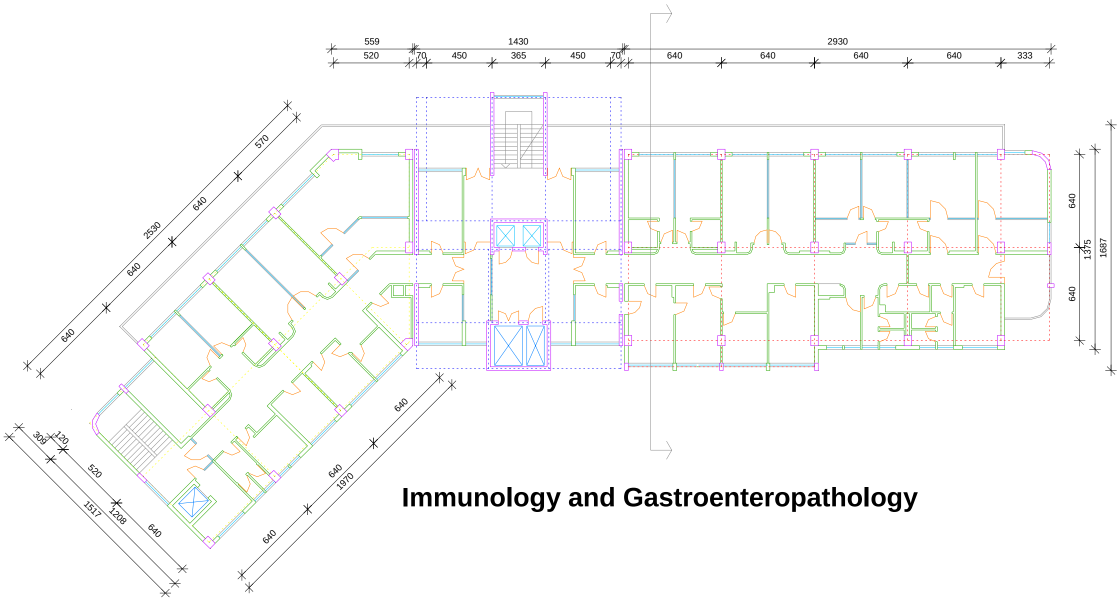


Second floor



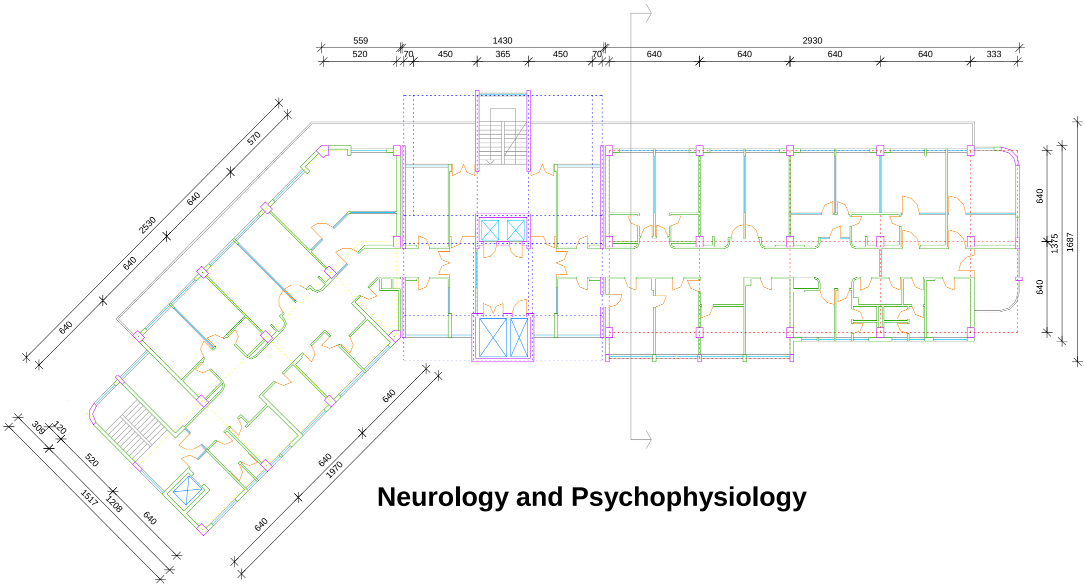
Pulmonology

Third floor



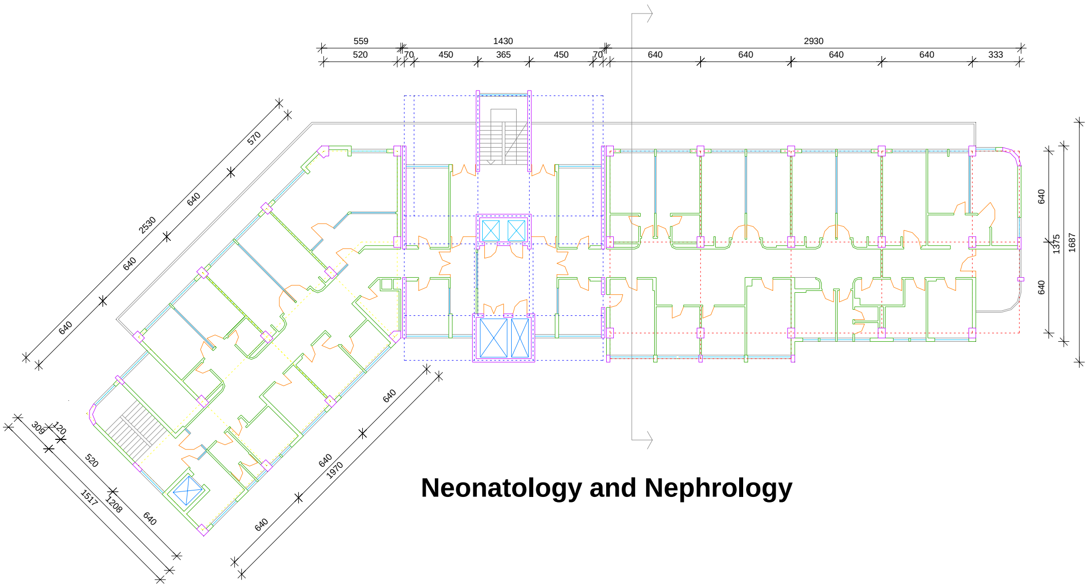
Immunology and Gastroenteropathology

Fourth floor



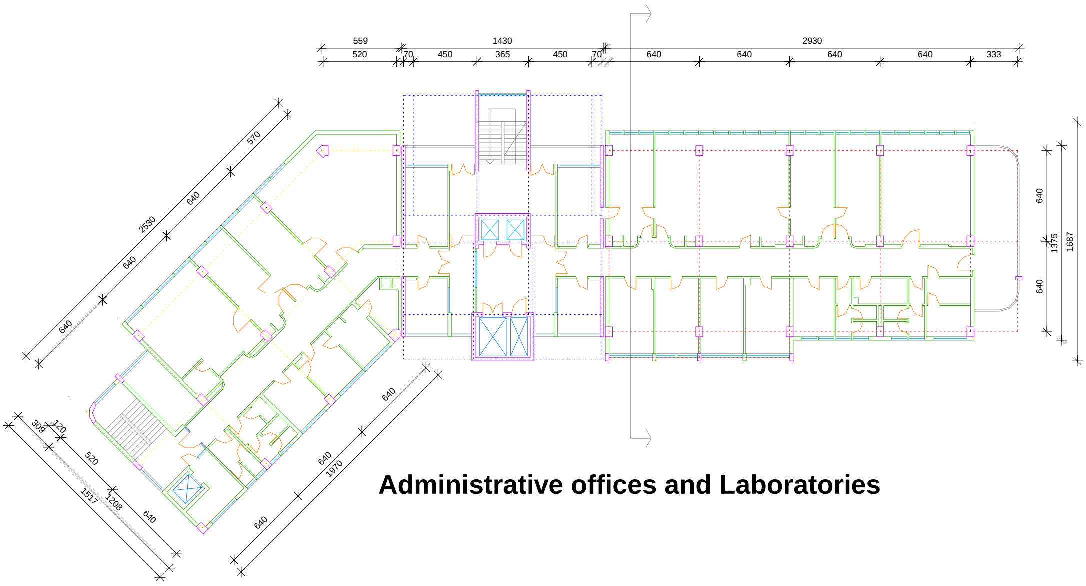
Neurology and Psychophysiology

Fifth floor



Neonatology and Nephrology

Sixth floor



Seventh floor

APPENDIX B: PHOTOS OF THE PAEDIATRIC CLINIC

Paediatric clinic (back view)

Outpatient waiting room (ground floor)

Corridor

Expansion joint

Patient's room (small)

Patient's room (big)

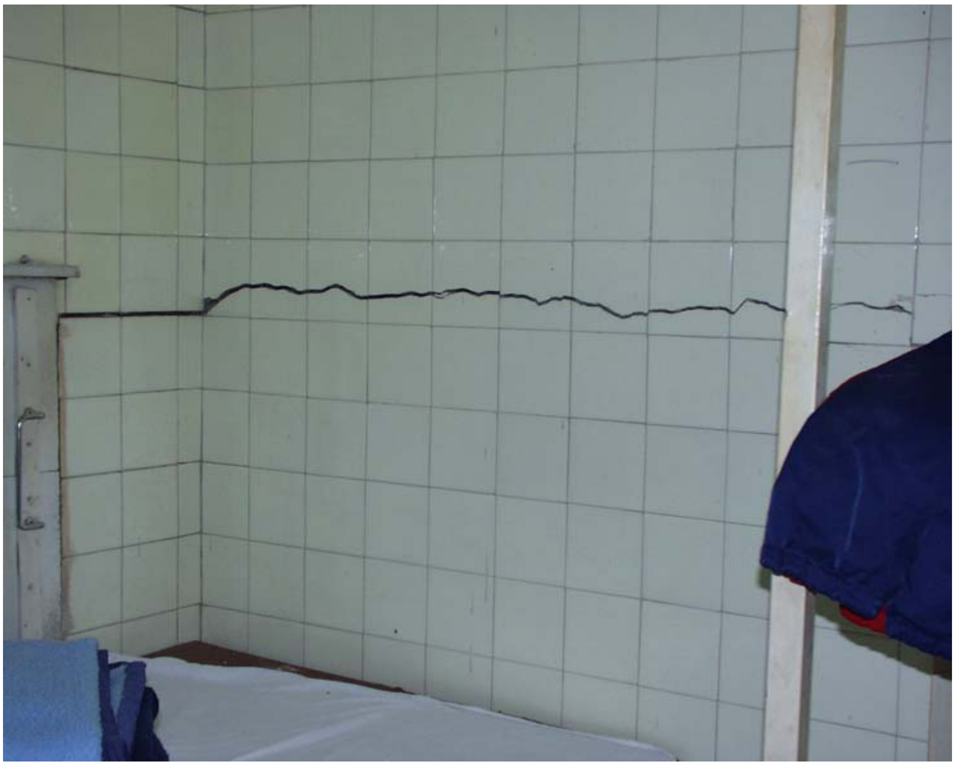
Laboratory

Laboratory

Basement

Suspended ceiling (basement)

Crack in the beam (basement)



Crack in the basement wall

APPENDIX C: HVE FORMS

HEALTH FACILITY VULNERABILITY EVALUATION

HVE–001 Form

FACILITY GENERAL DATA

Municipality:	**Centar**	**City:**	**Skopje**
Name:	**Paediatric Clinic, Clinical Centre "Skopje"**		
Address:	**Vodnjanska 17**		
Facility type:	**Clinic**		

Facility ID Number:	

Site (m^2):	**-**	**Built area (m^2)**	**7100**

Employees	**339**	**Capacity**	**230**
Doctors	75	Patients/day	**200/25 hospitalized**
Other medical staff	191	Number of beds	**230**
Administration	18		
Other	55		

SEISMIC EXPOSURE AND PREPAREDNESS

Maximum observed intensity (EMS-98)	**IX+**
Seismic zoning	**X**

Earthquake response plans:	☐ YES	☒ NO
Emergency supplies:	☒ YES	☐ NO
Earthquake response training:	☐ YES	☒ NO
Drills:	☐ YES	☒ NO

HEALTH FACILITY PERFORMANCE

Structural performance	☐ Good	☒ Average	☐ Poor
Nonstructural performance	☐ Good	☐ Average	☒ Poor
Administrative/Organizational performance	☐ Good	☒ Average	☐ Poor

Screeners: ______________________________ Date: ________________

____

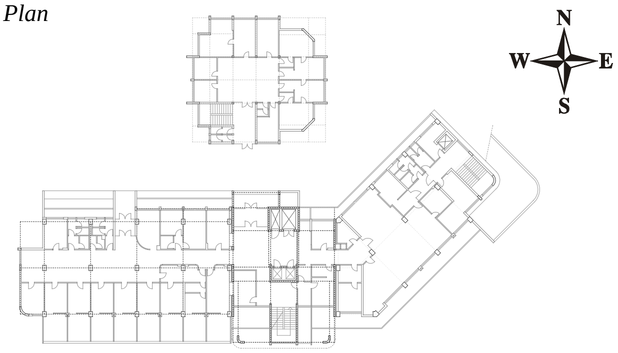
____

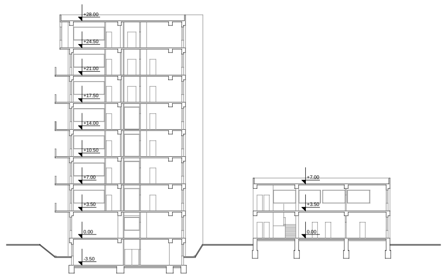
HEALTH FACILITY STRUCTURAL VULNERABILITY EVALUATION

HSVE–002 Form

Paediatric clinic, Clinical Centre "Skopje"

Plan





Elevation

Building General Data:

Building No.	1
Year built	1985 (1964 Code)
Building type	RC1
No. of stories	Basement+GF+7
Total bldg area [m^2]	7100
Building function	Hospital (Clinic)

Occupancy load		Soil Category (EC-8)			Existing damages			
Number of occupants		☐ **A** *Rock/Hard*	☒ **B** *Medium*	☐ **C** *Soft*	☒ Yes	☐ No	☐ Retrofit	☐ Reconst.
☐ 0–10	☐ 11–100				Please specify the year of intervention:			
☒ 101–1000	☐ 1000 +							

Building type		Vulnerability indices/modifiers						
		RC1	RC2	RC3.1	RC3.2	RC4	RC5	RC6
Basic vulnerability index		**31**	**23**	**33**	**35**	**27**	**25**	**32**
Periods of construction		< 1960		1960–1980		> 1980		

Building type		< 1960	1960–1980	> 1980
Code level		+8	0	-8
Maintenance	Good	0	0	0
	Bad	+2	+1	0
No. of stories	1-3	-2	-2	-2
	4-7	0	0	0
	8+	+4	+3	+2
Plan irregularity	Shape	+2	+1	0
	Torsion	+1	+1	0
Vertical irregularity		+2	+1	0
Soft story		+3	+2	+1
Short columns		+1	+1	0
Type of foundations	Beams	-2	0	0
	Con. Beams	0	0	0
	Footings	+2	0	0
Ground slope		+1	+1	+1
Soil conditions	A	-1	-2	-2
	B	0	0	0
	C	+2	+1	+1
TOTAL VULNERABILITY INDEX = <u>34</u>		**VULNERABILITY LEVEL = Low/<u>Moderate</u>/High**		
Comments:		Detailed evaluation required **YES** NO		

HEALTH FACILITY NONSTRUCTURAL VULNERABILITY EVALUATION

HNVE–001/1 Form

ARCHITECTURAL ELEMENTS

Building No. ____

Non-structural element	SI	Type of risk			Priority
		LS	*PL*	*LF*	
Divisions and partitions	Low	L	L	L	
	Mod	M	M	M	
	High	H	H	H	1
Interiors	Low	L	L	L	
	Mod	M	M	L	
	High	H	H	L	1
Ceilings	Low	L	L	L	
	Mod	M	M	M	
	High	H	H	H	1
Lighting	Low	L	L	L	
	Mod	H	L	L	
	High	H	M	M	2
Glass	Low	L	L	L	
	Mod	M	M	L	
	High	H	M	M	2
Facades, cornices, parapets	Low	L	L	L	
	Mod	M	M	L	
	High	H	H	L	
Chimneys	Low	L	L	L	
	Mod	M	M	L	
	High	H	M	M	

TOTAL PL SCORE	TPL = [**0** x L (1) + **2** x M (2) + **3** x H (3)]/NE = **2.6 (High)**
TOTAL LF SCORE	TLF = [**1** x L (1) + **2** x M (2) + **2** x H (3)]/NE = **2.2 (Moderate)**

Notes:

SI *– Seismic intensity (EMS-98): Low < 5; Mod = 5–8; High > 8*

Type of risk: ***LS*** *– Life safety;* ***PL*** *– Property loss;* ***LF*** *– Loss of function*

Risk ratings: ***L*** *– Low;* ***M*** *– Moderate;* ***H*** *– High*

NE – Number of elements

	Low	**Moderate**	**High**
Vulnerability level (TPL)	1–1.7	1.7–2.3	2.3–3
Consequences (TLF)	1–1.7	1.7–2.3	2.3–3

HEALTH FACILITY NONSTRUCTURAL VULNERABILITY EVALUATION

HNVE–001/2 Form

EQUIPMENT AND FURNISHINGS

Building No. ____

Non-structural element	SI	Type of risk			Priority
		LS	*PL*	*LF*	
Medical equipment	Low	L	M	M	
	Mod	M	H	H	
	High	M	H	H	4
Office equipment	Low	L	L	L	
	Mod	L	L	M	
	High	L	M	H	8
Furnishings	Low	L	L	L	
	Mod	L	M	L	
	High	L	M	L	8
Supplies	Low	L	L	M	
	Mod	L	M	M	
	High	M	H	H	4
Clinical files	Low	L	L	L	
	Mod	M	M	M	
	High	M	M	H	5
Pharmacy shelving	Low	L	L	L	
	Mod	H	M	H	
	High	H	H	H	
TOTAL PL SCORE	TPL = [**0** x L (1) + **3** x M (2) + **3** x H (3)]/NE = **2.4 (High)**				
TOTAL LF SCORE	TLF = [**1** x L (1) + **0** x M (2) + **4** x H (3)]/NE = **2.6 (High)**				

Notes:

SI *– Seismic intensity (EMS-98): Low < 5; Mod = 5–8; High > 8*

Type of risk: ***LS*** *– Life safety;* ***PL*** *– Property loss;* ***LF*** *– Loss of function*

Risk ratings: ***L*** *– Low;* ***M*** *– Moderate;* ***H*** *– High*

NE – Number of elements

	Low	Moderate	High
Vulnerability level (TPL)	1–1.7	1.7–2.3	2.3–3
Consequences (TLF)	1–1.7	1.7–2.3	2.3–3

HEALTH FACILITY NONSTRUCTURAL VULNERABILITY EVALUATION

HNVE–001/3 Form

BASIC INSTALATIONS AND SERVICES

Building No. ____

Non-structural element	SI	Type of risk			Priority
		LS	*PL*	*LF*	
Medical gases	Low	L	L	L	
	Mod	M	M	M	
	High	H	M	H	2
Industrial fuel	Low	L	L	L	
	Mod	M	H	M	
	High	H	H	M	
Electricity	Low	L	L	M	
	Mod	L	M	H	
	High	L	H	H	7
Telecommunication	Low	L	L	L	
	Mod	L	M	H	
	High	L	M	H	8
Plumbing system	Low	L	L	L	
	Mod	M	M	M	
	High	M	M	H	5
HVAC	Low	L	M	L	
	Mod	L	M	L	
	High	M	H	M	
Fire detection and suppression	Low	L	M	M	
	Mod	L	H	H	
	High	M	H	H	4
Elevators	Low	L	L	L	
	Mod	L	M	M	
	High	M	M	M	5
TOTAL PL SCORE	PL = [**0** x L (1) + **4** x M (2) + **2** x H (3)]/NE = **2 (Moderate)**				
TOTAL LF SCORE	LF = [**0** x L (1) + **1** x M (2) + **5** x H (3)]/NE = **2.8 (High)**				

Notes:

***SI** – Seismic intensity (EMS-98): Low < 5; Mod = 5–8; High > 8*

*Type of risk: **LS** – Life safety; **PL** – Property loss; **LF** – Loss of function*

*Risk ratings: **L** – Low; **M** – Moderate; **H** – High*

NE – Number of elements

	Low	Moderate	High
Vulnerability level (TPL)	1–1.7	1.7–2.3	2.3–3
Consequences (TLF)	1–1.7	1.7–2.3	2.3–3

HEALTH FACILITY ADMINISTRATIVE/ORGANIZATIONAL VULNERABILITY EVALUATION

HOVE–001/1 Form

CAPABILITY ASSESSMENT

Existing	Medical services	Importance	Capability: Assigned Personnel	Emergency Supplies	Medical Equipment	Backup Systems
☐	*Trauma and Orthopaedics*	5				
x	*Intensive Care Unit*	5	2	2	2	2
☐	*Emergency Care*	5				
x	*Diagnostic Imaging*	5	2	2	2	2
☐	*Surgery*	5				
☐	*Blood Bank*	5				
x	*Paediatrics*	4	2	2	2	2
☐	*Urology*	5				
☐	*Haemodialysis*	4				
☐	*Gynaecology and Obstet.*	3				
x	*Neonatology*	3	2	2	2	2
x	*Respiratory Medicine*	2	2	2	2	2
☐	*Internal Medicine*	3				
☐	*Infectious Diseases*	3				
☐	*Othorinolaringology*	1				
☐	*Ophthalmology*	2				
x	*Oncology*	1	2	3	2	2
x	*Neurology*	3	2	2	2	2
x	*Psychiatry*	1	2	2	2	2
☐	*Dermatology*	1				
☐	*Dental Medicine*	1				
☐	*Physiotherapy and Reh.*	1				
x	*Recovery (inpatients)*	5	2	2	2	2
x	*Laboratory*	4	2	2	2	2
☐	*Sterilization*	5				
☐	*Pharmacy*	5				
x	*Nutrition*	5	2	2	2	3
x	*Administration*	3	2	2	2	2
x	*Laundry services*	4	2	2	2	3

IMPORTANCE

5 Indispensable
4 Very necessary
3 Necessary
2 Preferable
1 Dispensable

CAPABILITY

1. **Optimal –** Efficient allocation of resources and personnel
2. **Adequate –** Acceptable allocation of resources and personnel; operations can proceed normally
3. **Minimal –** Barely acceptable allocation of resources or personnel; operations can proceed with certain restrictions
4. **Inadequate –** Unacceptable assignation of resources or personnel; severe limits on the activity in question or impossibility of carrying out the activity in question

Overall capability rating

High ☐
Moderate ☒
Low ☐

SPATIAL DISTRIBUTION OF SERVICES

Medical services interrelationship matrix

1 No relationship
2 Indirect relationship
3 Direct relationship
4 Key relationship

	Administration	Outpatient Care	Radiology	Clinical Laboratory	Pathological Anatomy	Physiotherapy	Emergency Care	Surgery	Obstetrics	Sterilization	Intensive Care	Hospital Admissions	Staff Dressing Room	Kitchen	Maintenance	Machine Room
Outpatient Care	3															
Radiology	3	4														
Clinical Laboratory	3	4	2													
Pathological Anatomy	3	2	1	3												
Physiotherapy	3	3	4	1	1											
Emergency Services	3	3	4	4	4	1										
Surgery	3	3	4	4	4	1	4									
Obstetrics	3	3	4	4	4	1	4	4								
Sterilization	3	3	2	2	2	1	4	4	4							
Intensive Care	3	3	4	4	4	1	4	4	4	3						
Admissions	3	1	3	3	4	3	4	4	4	4	4					
Staff Dressing Room	3	2	2	2	2	2	2	2	2	2	2	2				
Kitchen	2	1	2	2	2	2	2	2	2	2	4	3	3			
Maintenance	2	1	2	2	2	2	2	2	2	3	2	2	3	3		
Machine Room	2	1	2	2	2	2	2	2	2	2	2	2	3	4	4	
Laundry Room	2	1	2	2	2	2	2	2	2	3	2	4	3	4	4	4

Good	☐
Average	☒
Poor	☐

FACILITY EXTERNAL INTERDEPENDANCE (LIFELINES)

Access to Facility	good	average	poor
Vehicle	☐	☐	☒
Pedestrian	☐	☒	☐

Helicopter Landing		
	Surface	☒
	Rooftop	☐

Electric power	
Community utility	☒
Backup system	
Partial load of facility and operation	☒
Full load of facility and operation	☐

Heating system	
Community utility	☐
On-site utility	☒

Water Supply	regular	backup
Community utility	☒	☐
On-site well	☐	☐
On-site reservoir	☐	☐
Water treatment installation	☐	☐

Communication	regular	backup
Telephone	☒	☒
Radio connection	☐	☐
Internet	☐	☐

Cooling System	
Integrated system (HVAC)	☐
Dispersed system	☒

Overall rating	good	average	poor
Water Supply	☐	☐	☒
Electric power	☒	☐	☐
Lifelines Maintenance	☐	☒	☐