Evaluation and upgrading of the seismic safety of Paks NPP

Dr. Tamás János Katona

Chief Engineer Paks NPP

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MVM Nuclear Power Plant Paks Ltd.

Paks NPP and its value

four WWER-440/213 units, 2000 MWe, ~20% of domestic generating capacities, ~ 43% of domestic production

Safety – paramount, Competitiveness: Power up-rate 500MWe, 20 years extension of operational lifetime, strong public support,

the first 30 years of operation was a continuous struggling for safety

What does it mean: safe design?

The design has to ensure the basic nuclear safety functions, i.e.

•the control of the reactivity in the reactor and spent fuel pool, i.e. the ability to shutdown the reactor and maintain the sub-criticality after the earthquake,

•to cool down and heat removal from the core and spent fuel,

•to maintain the containment function for the reactor and spent fuel, i.e. limit the release of radioactive substances into the environment.

The functions have to be maintained for the earthquakes within the design basis envelope and with some extent for the earthquakes with parameters exceeding the design basis one.

mvm paks nuclea

Seismic hazard, design basis and seismic safety in historical perspective

1980 | 1990 | 2000 | 2010

1962 site selection

1986 start of the hazard re-evaluation

1992 preliminary conservative RLE

1996 new DBE PGA=0.25g approved

Extensive site evaluation

Microseismic monitoring + updating

Intensity-based, credible historical earthquake

Deterministic, PGA=0.15g, Inst. of Earth Physics Moscow

Simplified PSHA assessment

Comprehensive PSHA assessment

Reviews

1999 1st PSR

2004 review in the frame of EIA of LR

2007 2nd PSR

2011 Targeted Safety Reassessment

Seismic upgrading

Upgrading for DBE

Ensuring Current Licensing Basis

Easy-fix program for preliminary conservative input

Measures identified by 1st PSR

Measures identified by Seismic PSA

Measures identified by 2nd PSR

Measures identified by TSR

PHARE and IAEA TC support (experts from US, GB, France, Germany, Italy and Belgium), Several IAEA review missions

Beyond DB but no Fukushima syndrome

Seismic PSA: identification of some week links and beyond design base issues, like liquefaction

PSR NS-R-1, par. 5.22 sufficient margin

Focus on beyond design base issues

How to achieve the seismic safety?

1. Evaluation of the seismic hazard of the site that includes the associated with earthquake events, e.g. liquefaction;
2. Development of the design basis earthquake characteristics;
3. Identification of the structures, systems and equipment, which are needed for ensuring that basic safety functions. Seismic/safety classification;
4. Adequate design (load and pressure bearing SCs) and qualification of active and non-metallic components;
5. Development of pre-earthquake preparedness and post-earthquake measures;
6. Installation of seismic instrumentation, OBE exceedance criteria;
7. Safety assessment: Evaluation of the safety, i.e. quantification of the safety margins, calculation of the core damage frequency due to earthquake.
8. Ensuring seismic safety during operation: plant internal rules, seismic housekeeping.
9. Periodic safety reviews.

Summary of the program

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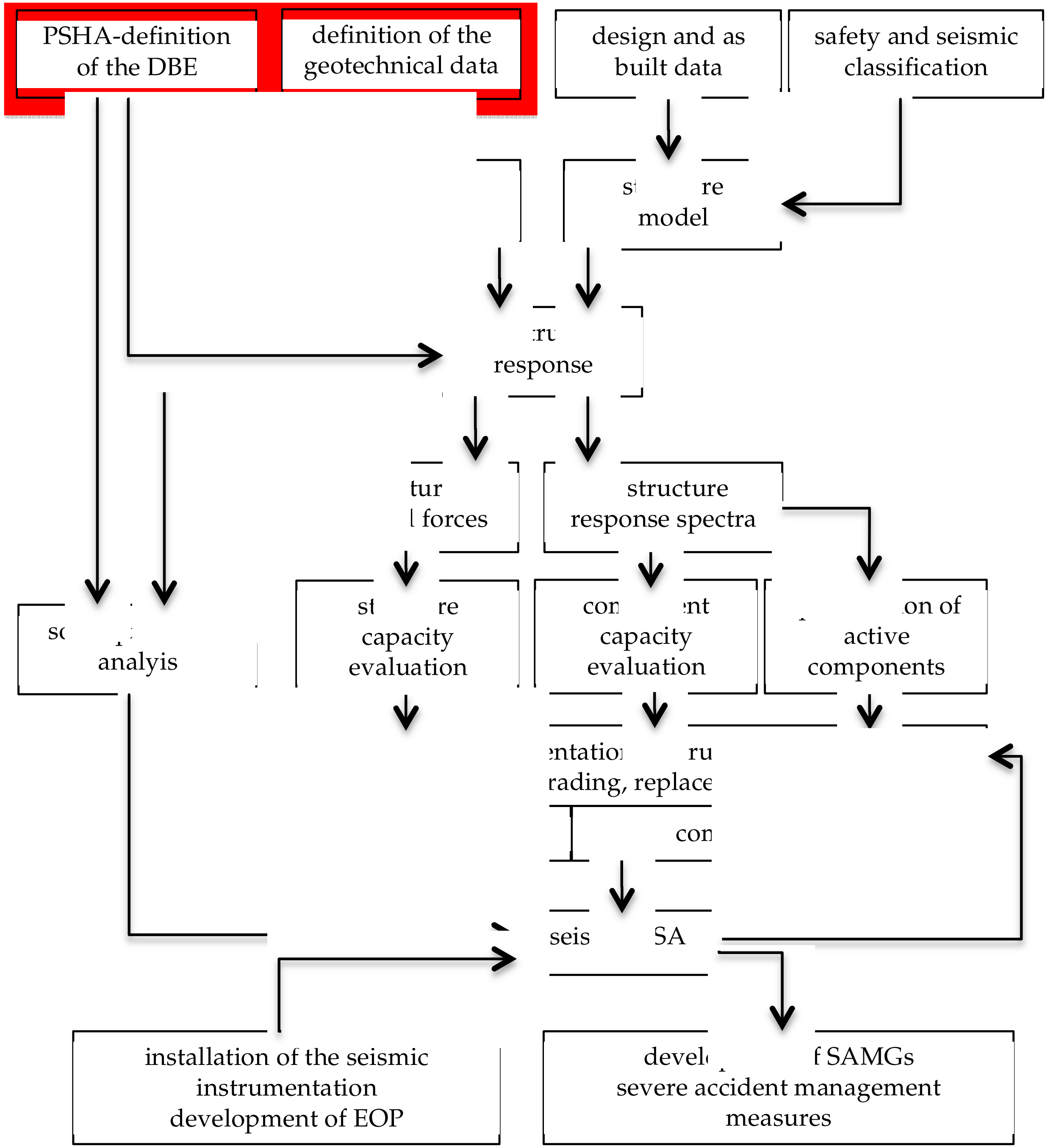


Definition of the DBE

Past regulation

•1962 MSK-64 V+I, no seismic design

•1996 in accordance with SG-S-1 and SG-D-15 (footnote), 10-4/a event and site specific response spectra

•1997 new Nuclear Safety Regulations – 10-4/a event, site specific free-field response spectra, site soil conditions have to be accounted

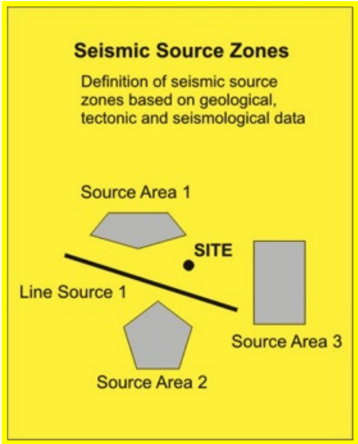
Recent regulation (2011):

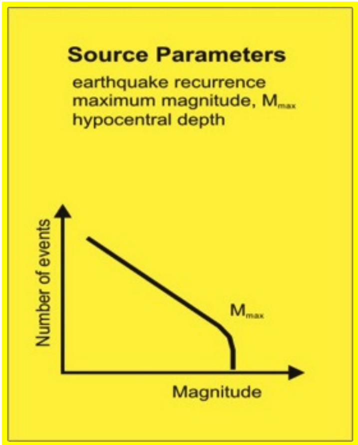
•**Site evaluation - in accordance with IAEA SSG-9**

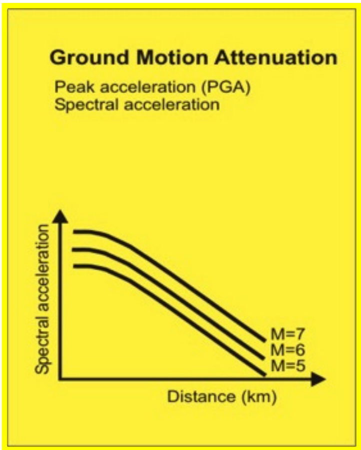
•**Design Base Earthquake -** updated Nuclear Safety Regulation (Gov. Decree 108/2011) of 0.005 non-exceedance probability for the lifetime on median hazard curve, free-field response spectra, site soil conditions have to be accounted, **cliff-edge effect has to be excluded** (Reg. Guide 1.208 and ASCE/SEI 43-05)

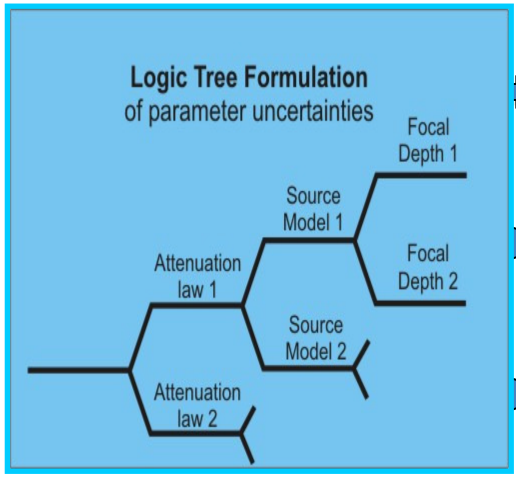
PSHA process

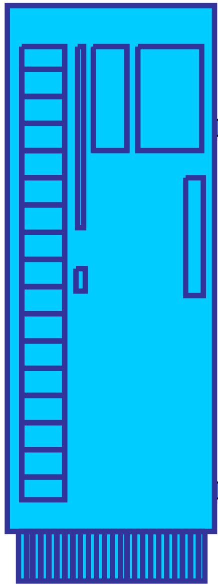
five (+) steps are involved in the assessment of seismic hazard

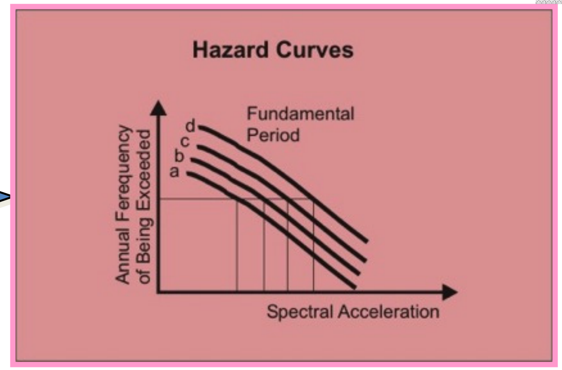


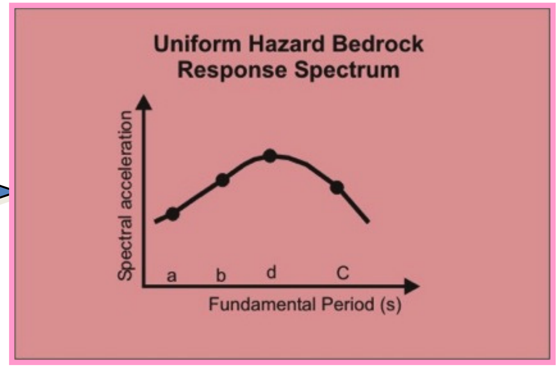






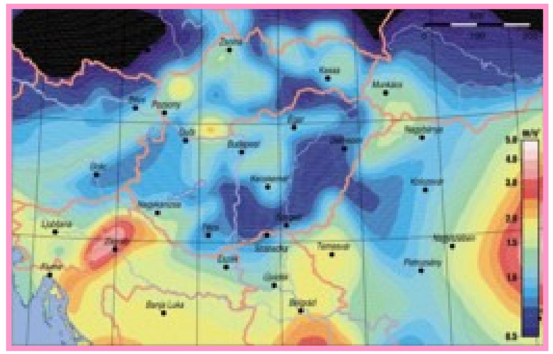






See Tóth L., Győri E., Katona TJ (2008), Current Hungarian Practice of Seismic Hazard Assessment. In: OECD NEA Workshop: Recent Findings and Developments in Probabilistic Seismic Hazard Analysis (PSHA) Methodologies and Applications: Workshop Proceedings, Lyon, France, 2008.04.07-2008.04.09.pp. 313-344. Paper NEA/CSNI/R(2009)1.

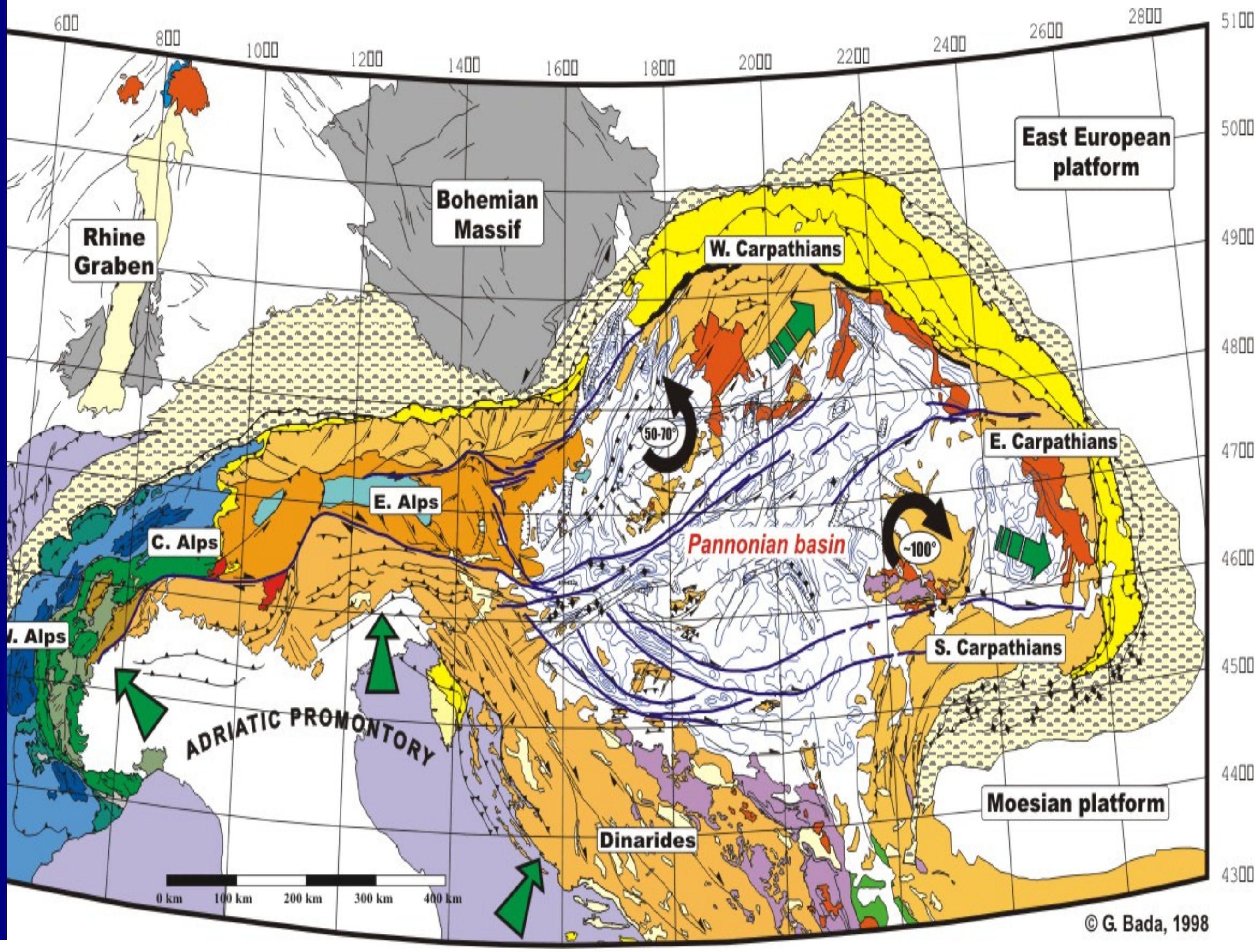
(PSHA Level 2+ or 3 according to NUREG/CR-6372 (SSHAC – Senior Seismic Hazard Analysis Committee Report: Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, 1997)



Geological and tectonic environment

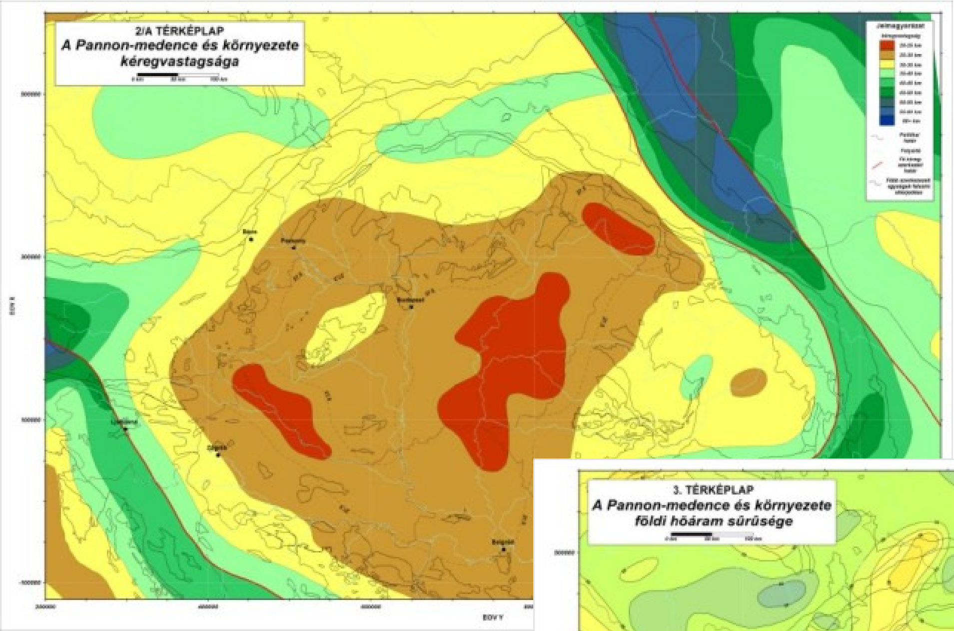
Stress accumulations and recent deformations in the Pannonian basin are governed by the interaction of plate boundary and intraplate forces that include as the dominant source of compression: the counter-clockwise rotation and N-NE directed indentation, of the Adria microplate - otherwise known as "Adria-push". In combination with buoyancy forces associated with elevated topography, and with lithospheric heterogeneities in the surrounding orogens that result in a complex pattern of ongoing tectonic stress and deformation activity transferred far into the Pannonian basin.

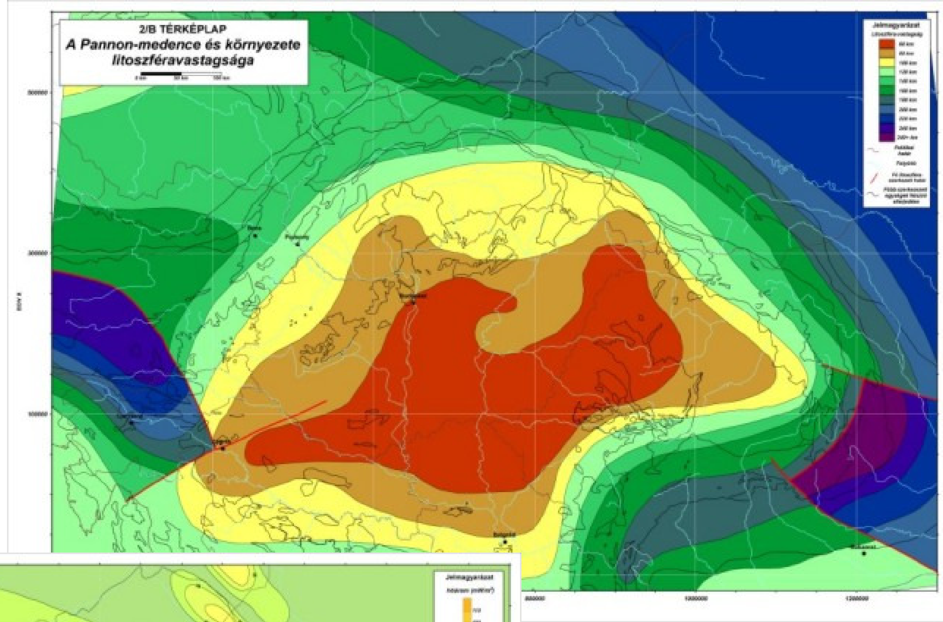
Complex pattern of ongoing tectonic stress and deformation

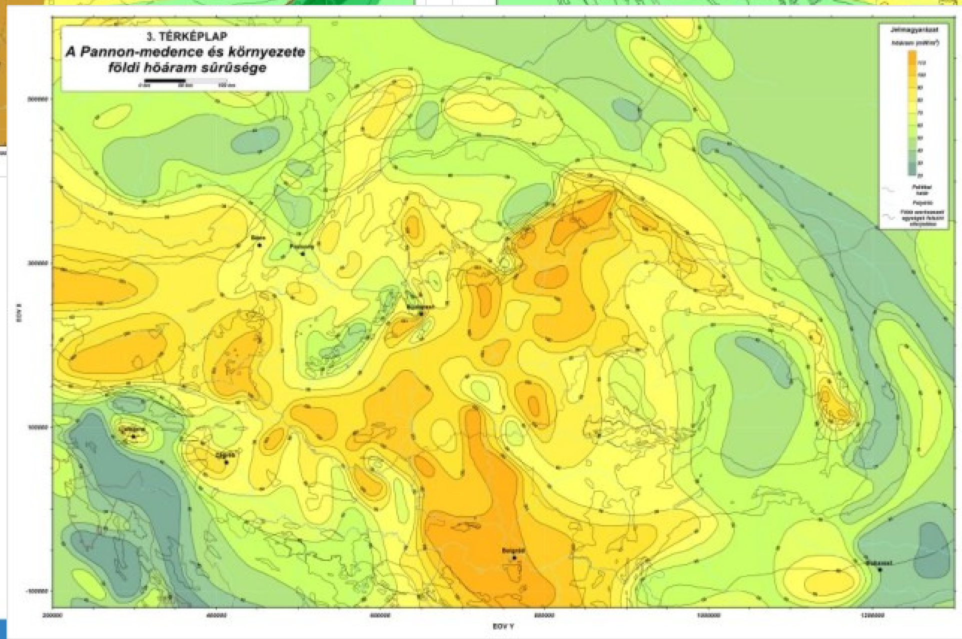


Crust, lithosphere depth, thickness and temperature gradient in Pannonian basin

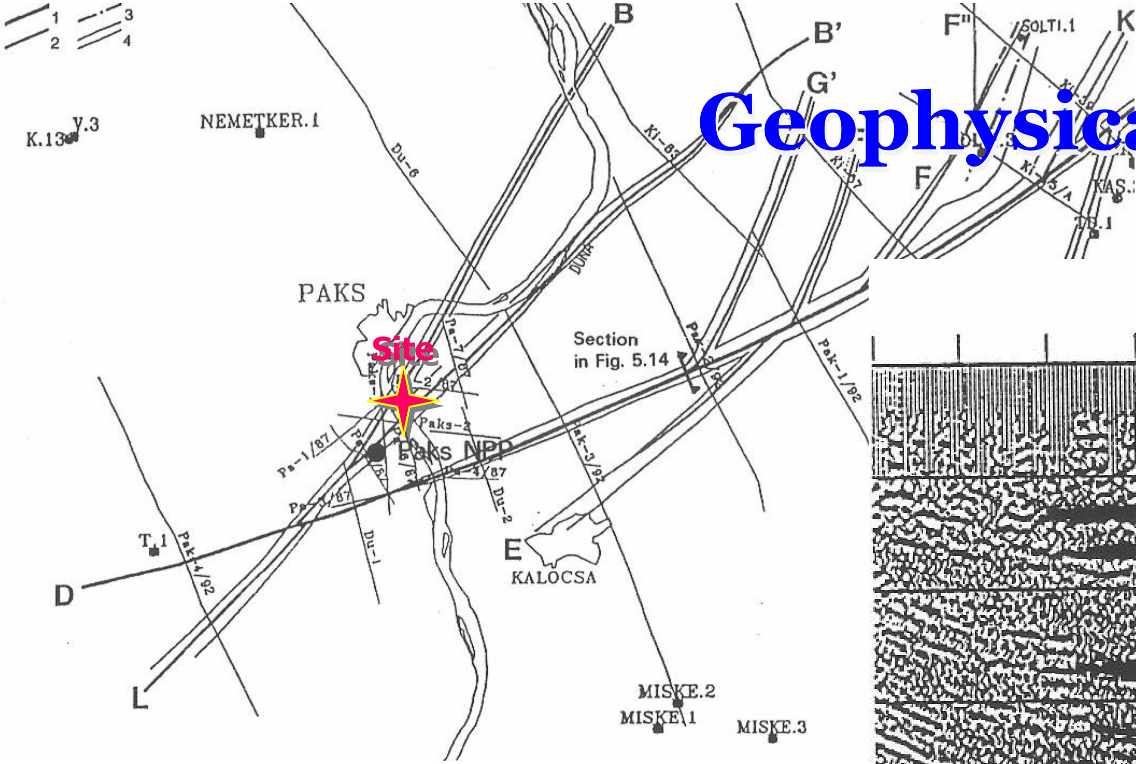
(see e.g. Frank Horvath & Gabor Bada, **http://geophysics.elte.hu/atlas/geodin_atlas.htm***)*

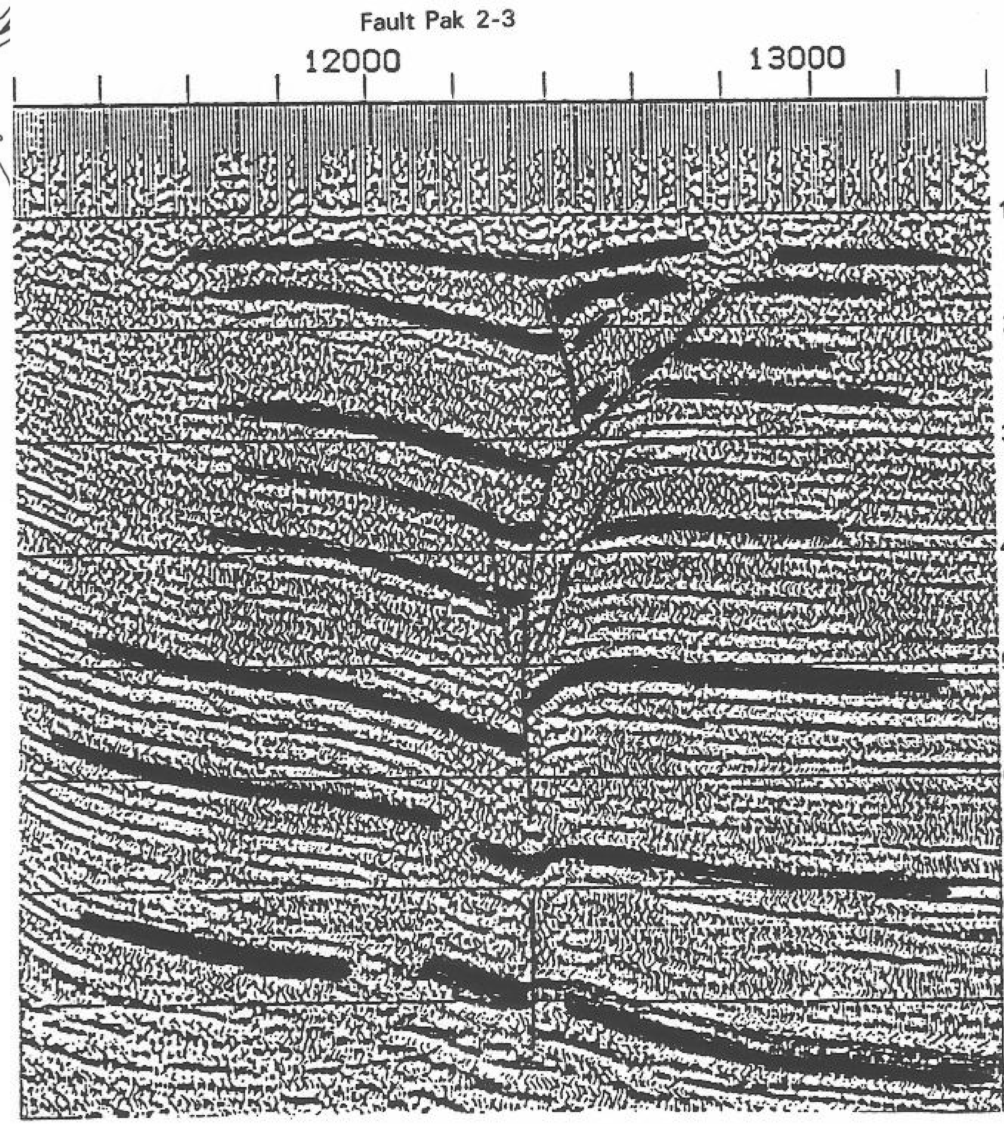






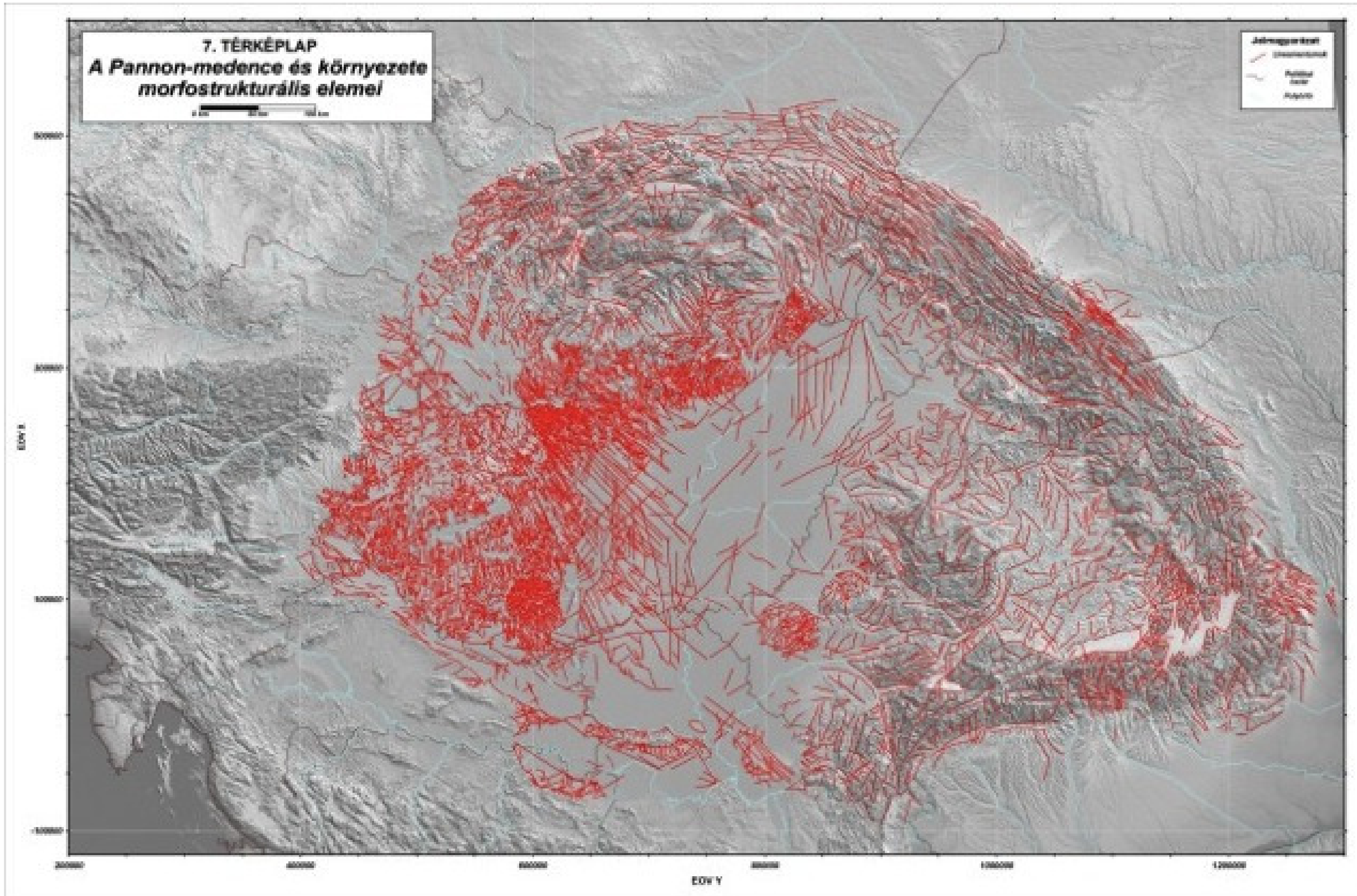
Geophysical investigations





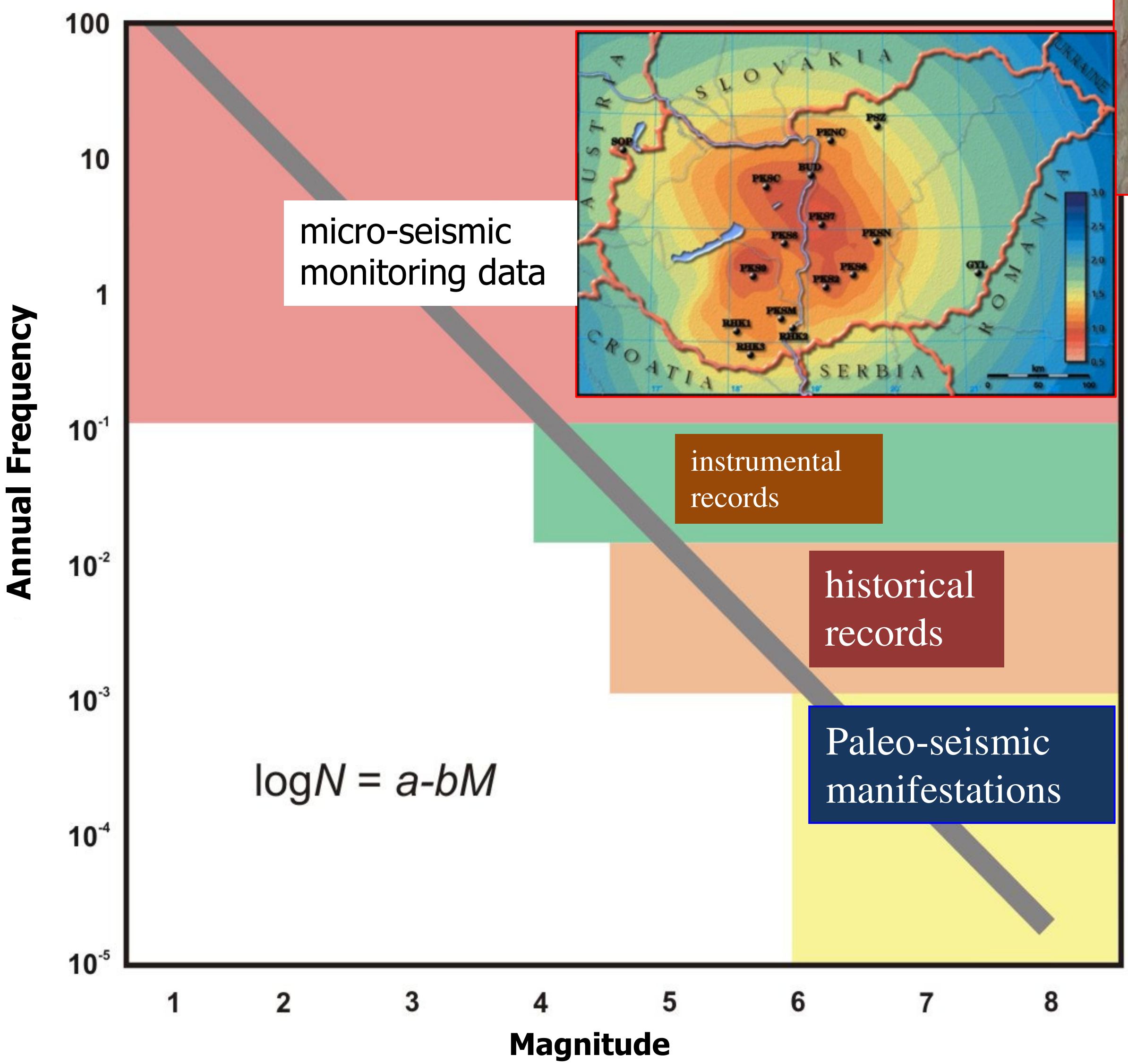
Geophysical profile
PAK-2

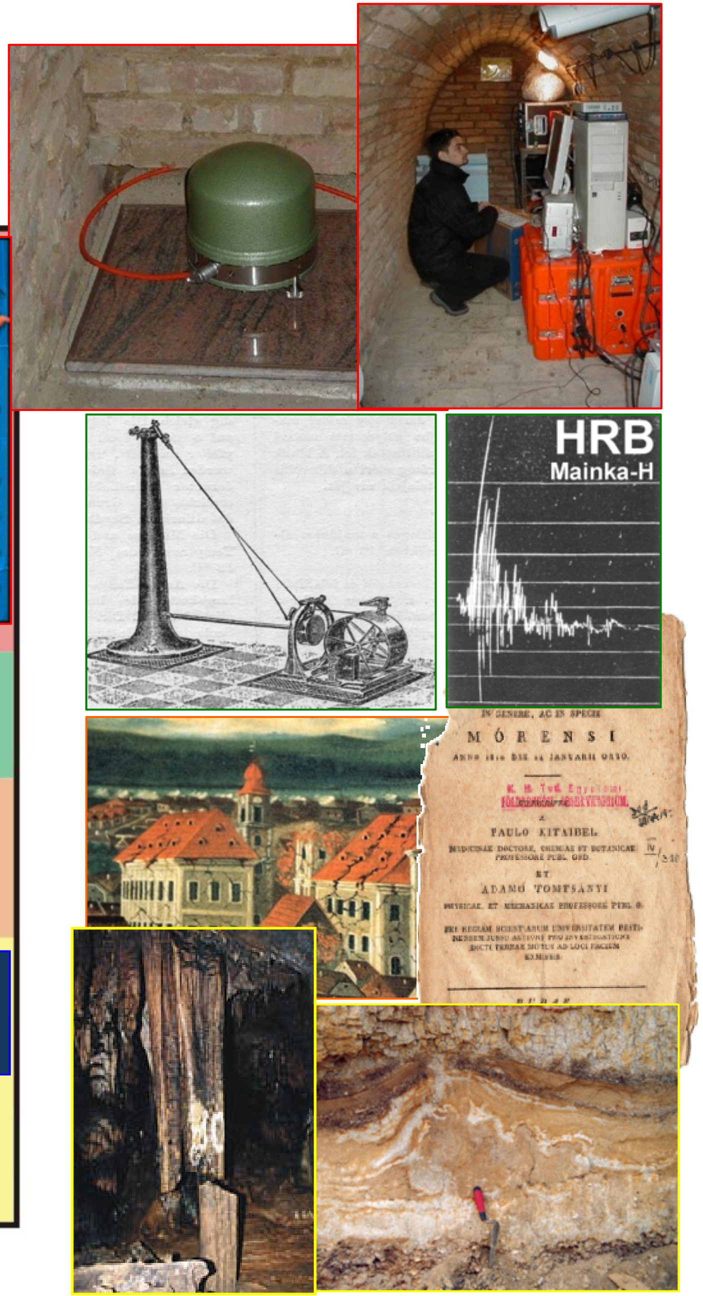
Geology and tectonics: Faults



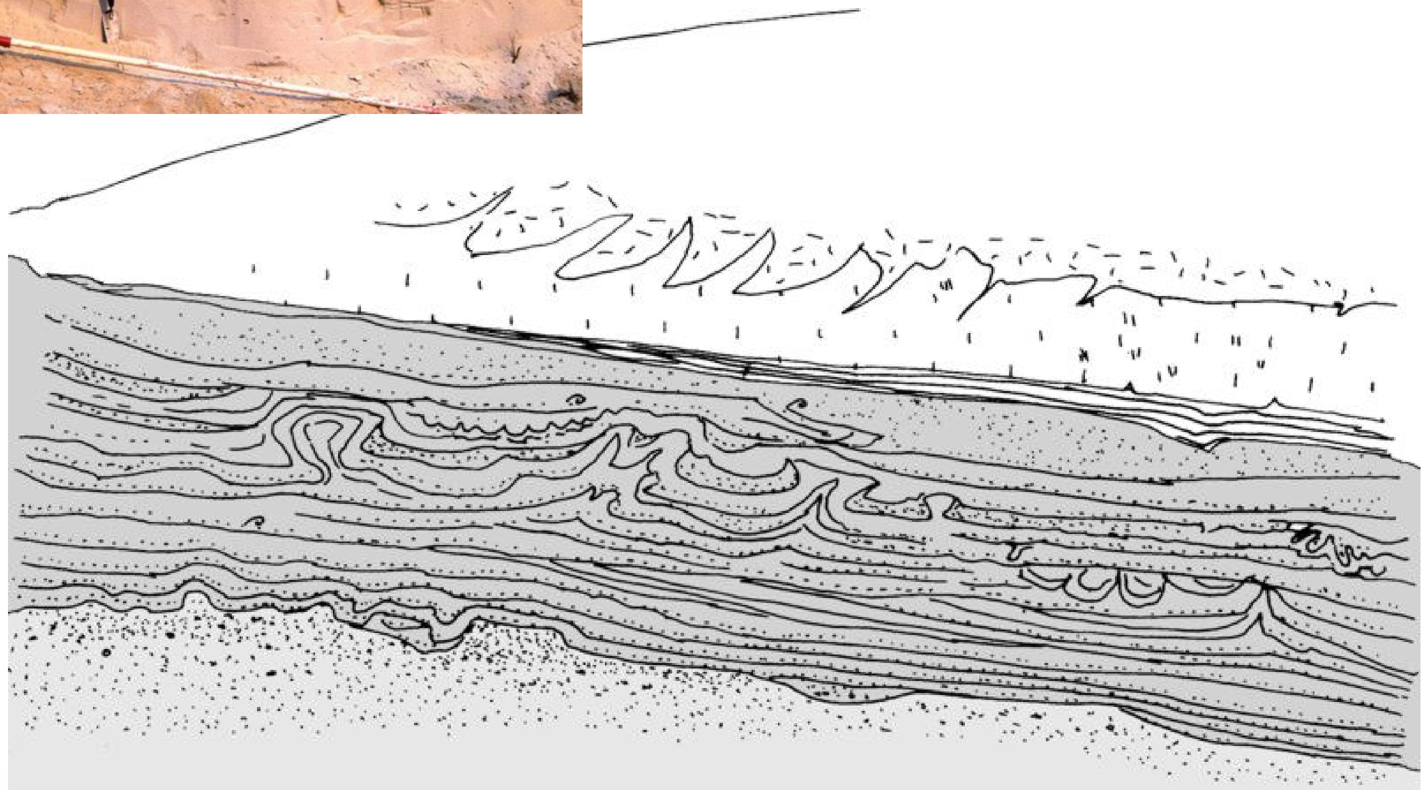
(see e.g. Frank Horvath & Gabor Bada, http://geophysics.elte.hu/atlas/geodin_atlas.htm*)*

Seismological Database



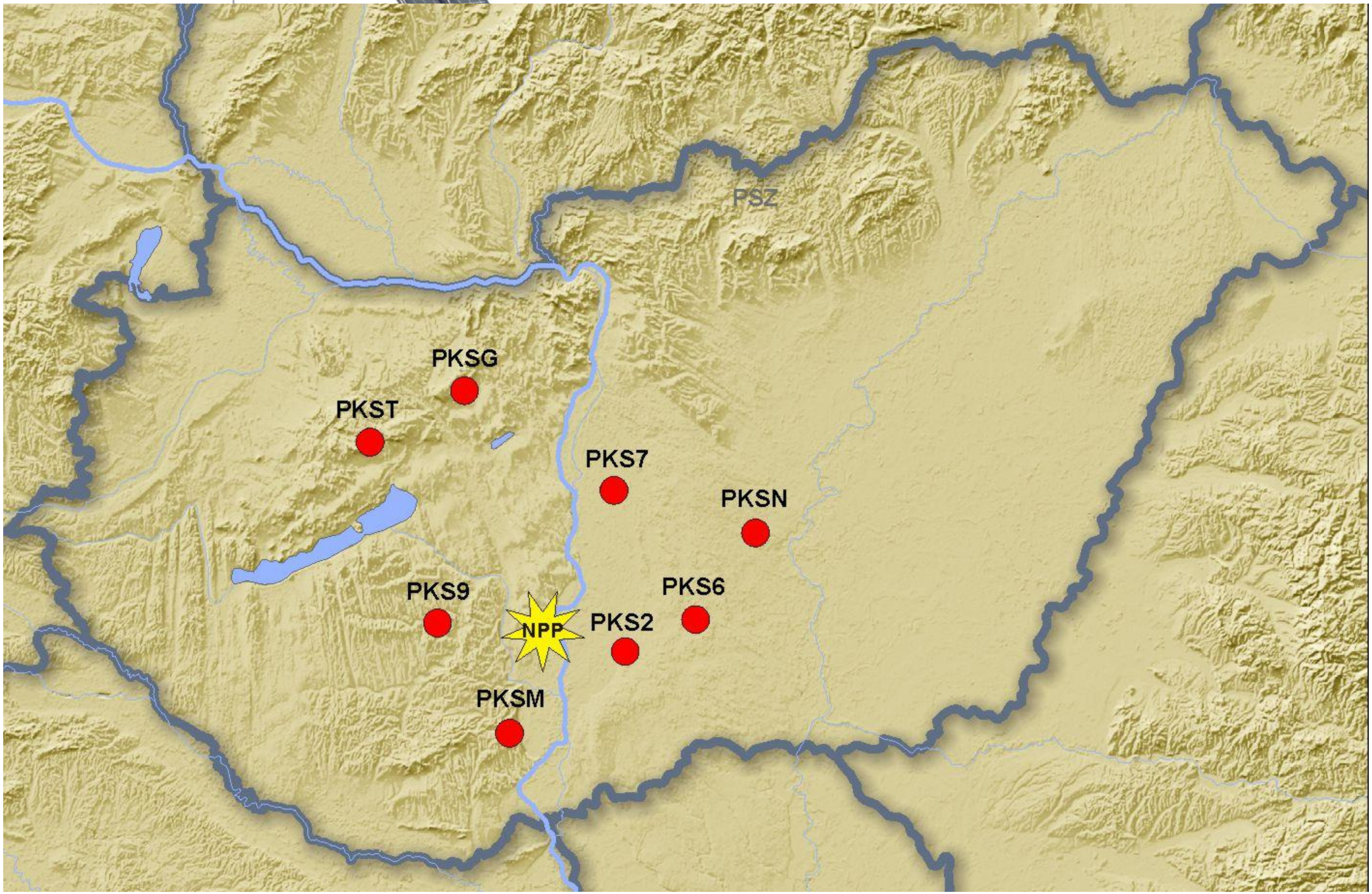


Paleo-seismological information



Bicske (Hungary)
After Magyari et al.

Micro-seismic monitoring



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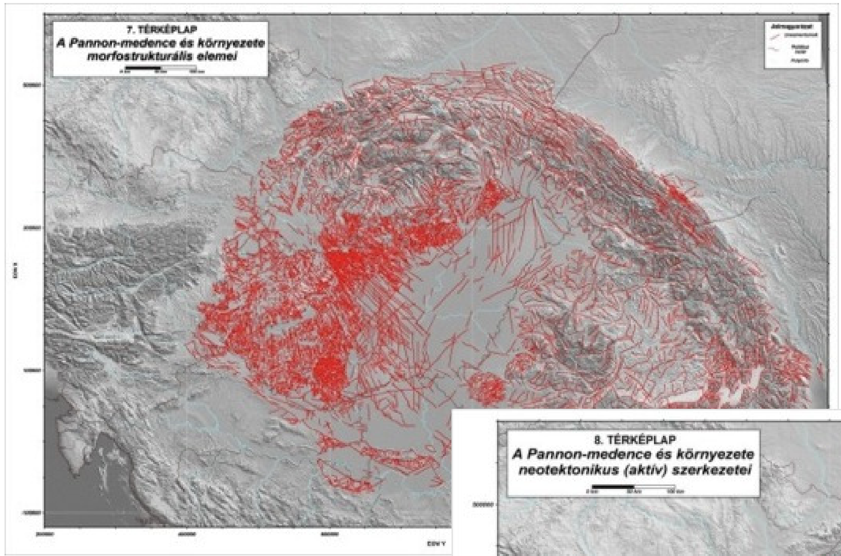
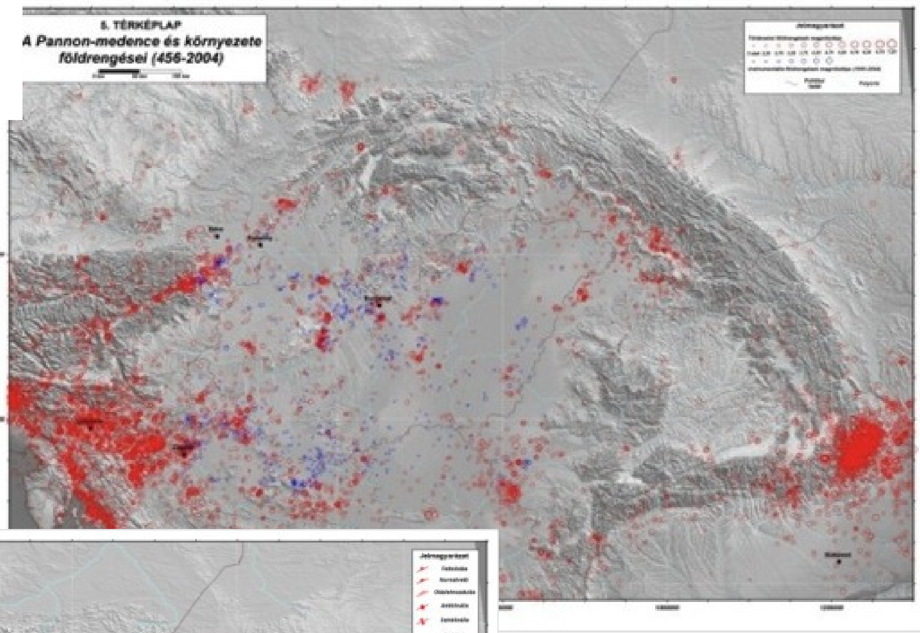
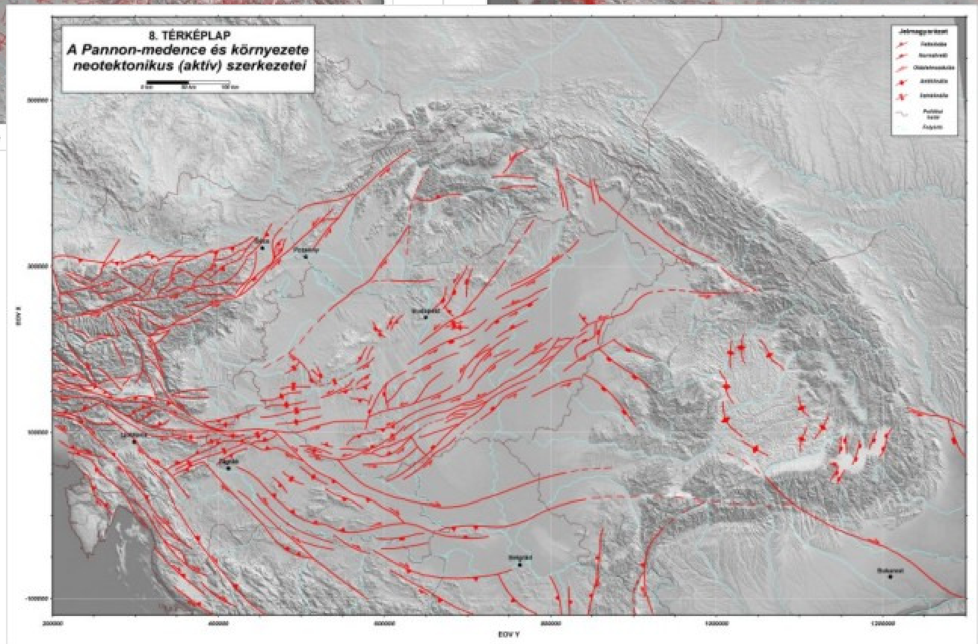
Faults and seismicity Mid Hungarian Fault

(see e.g. Frank Horvath & Gabor Bada, http://geophysics.elte.hu/atlas/geodin_atlas.htm*)*

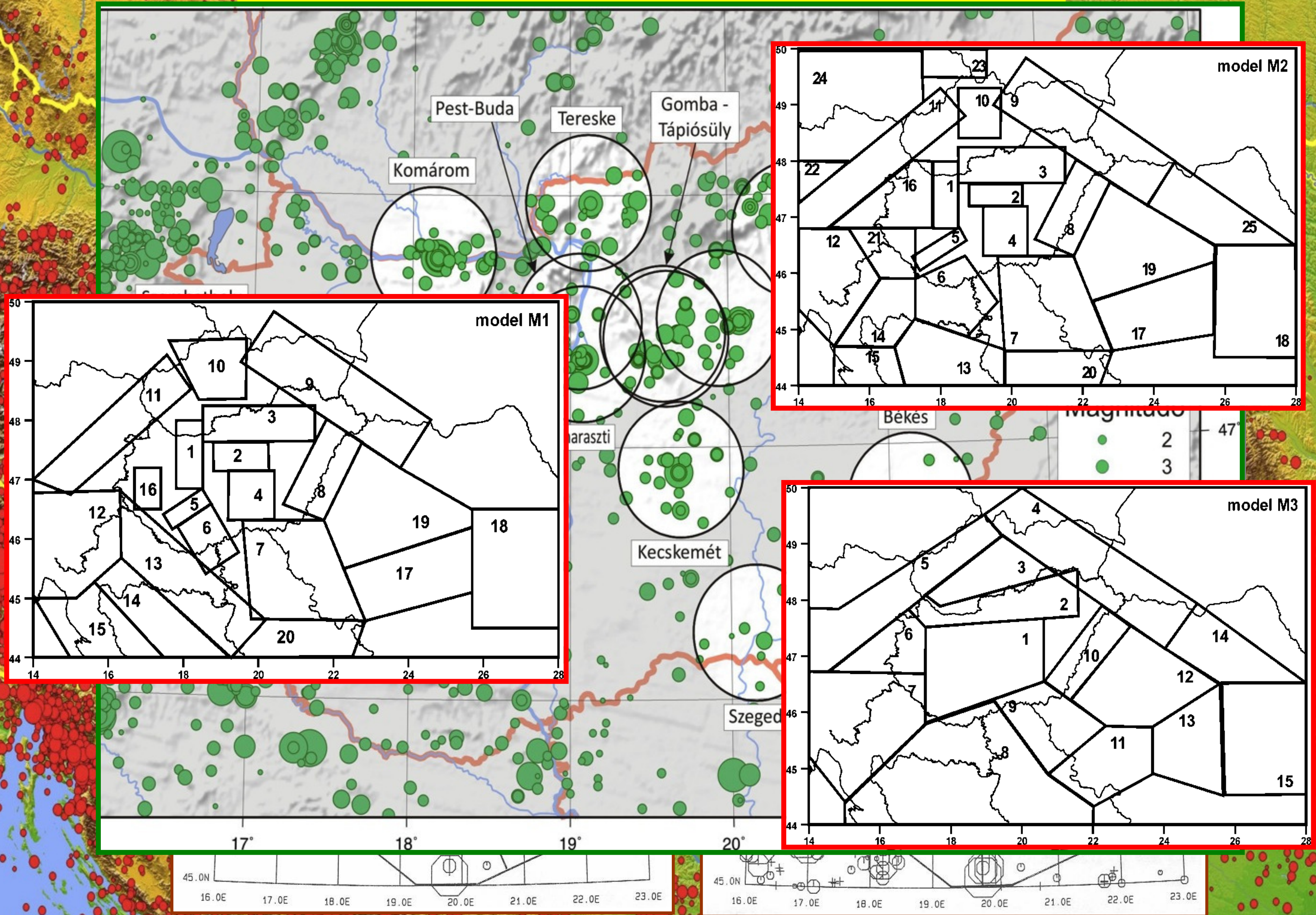




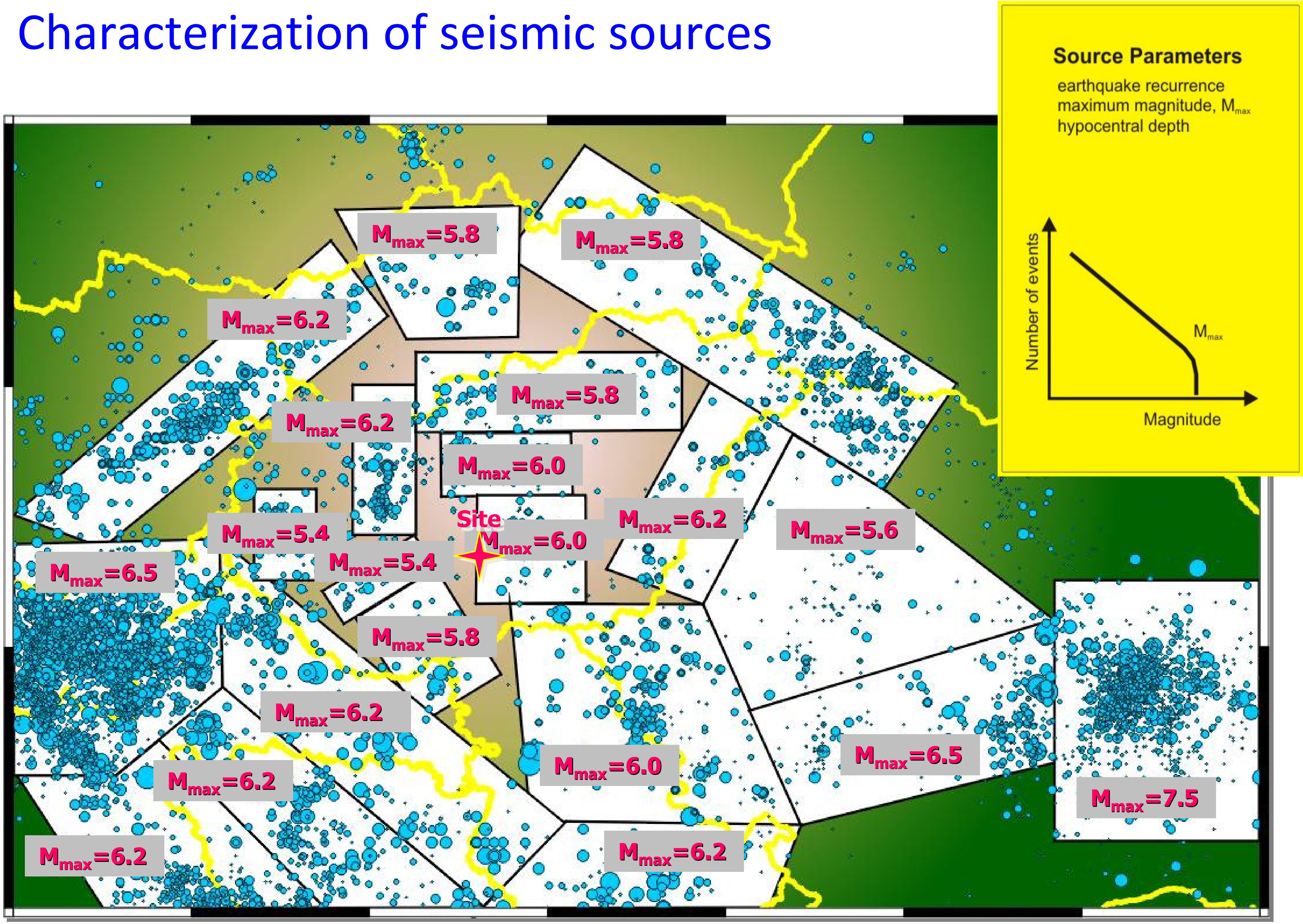


Identification of seismic sources

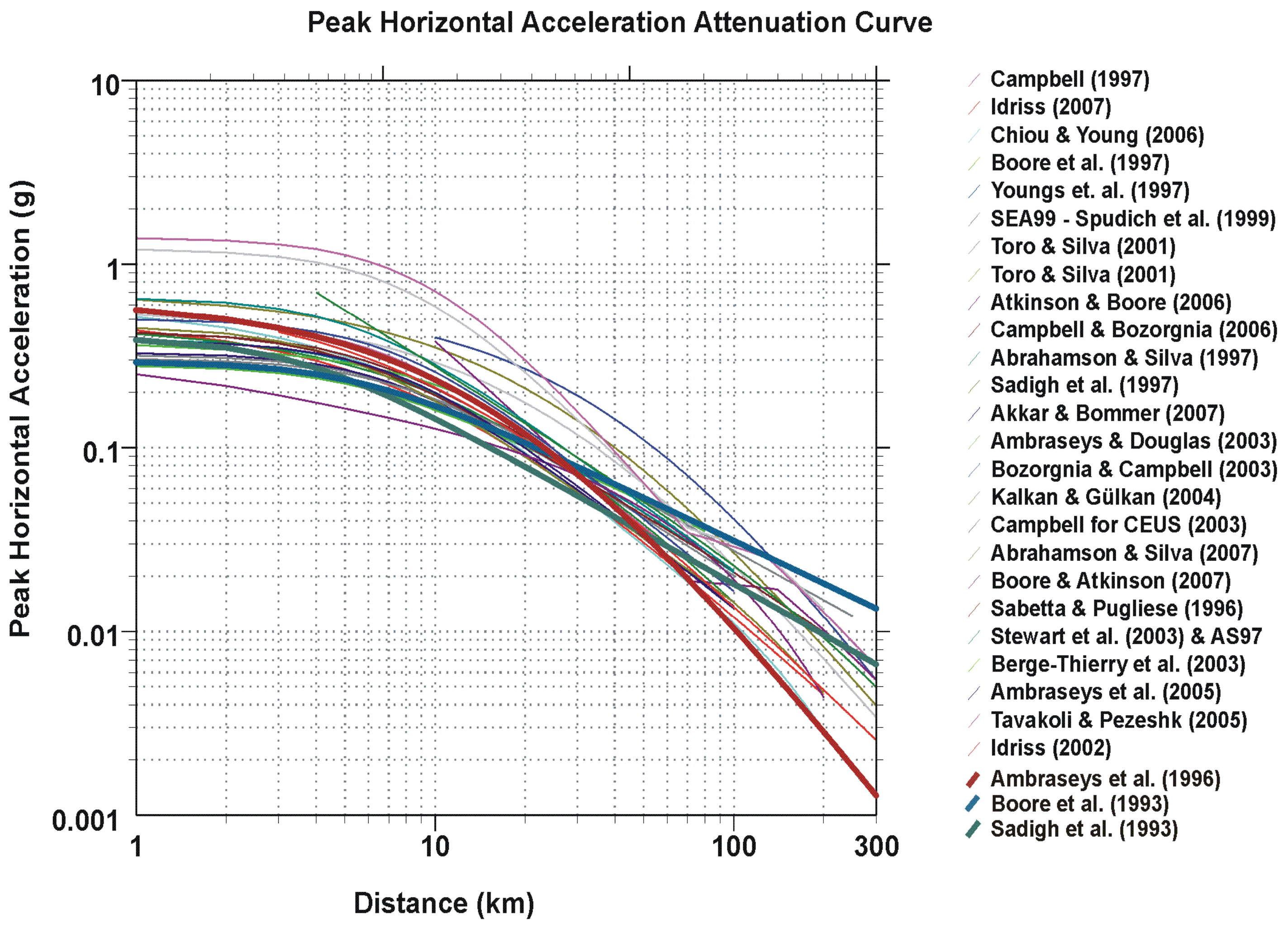
Significant epistemic uncertainty



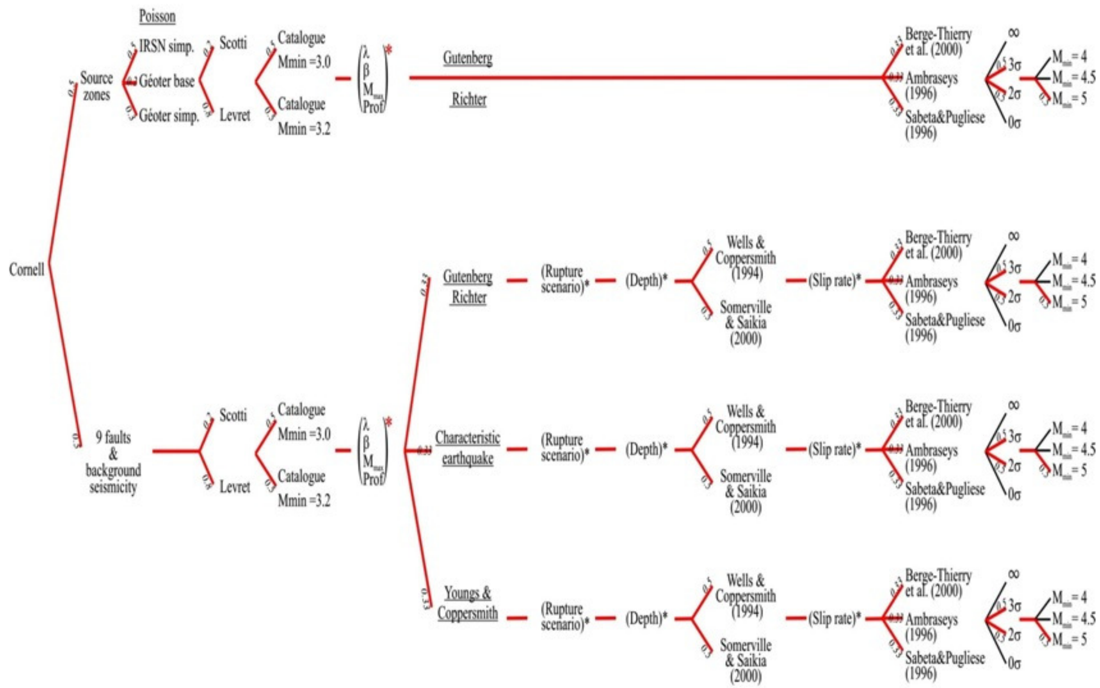
Characterization of seismic sources

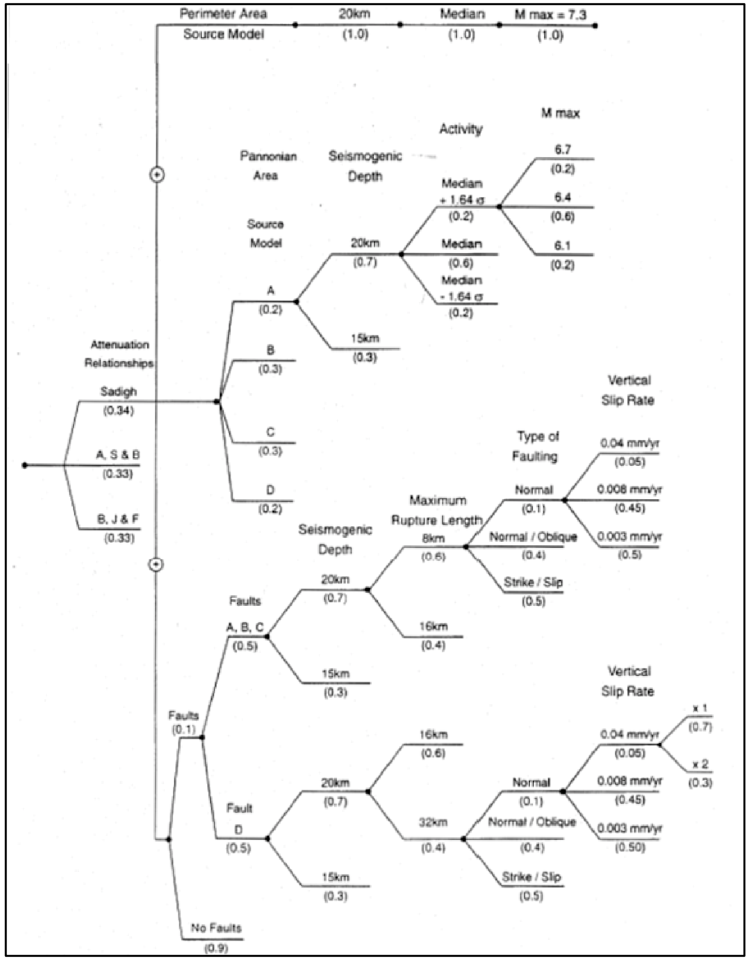


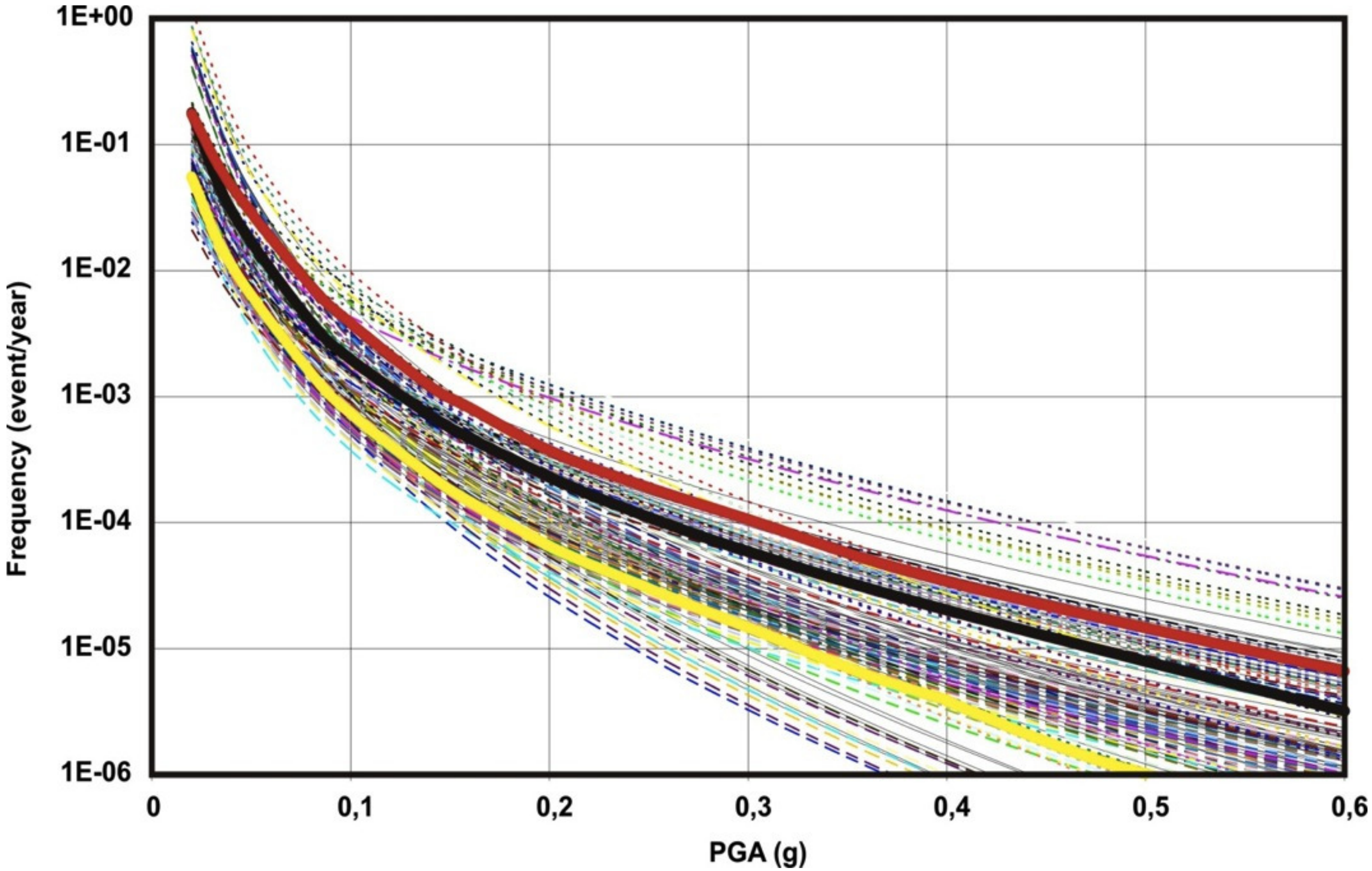
PGA attenuation



Modeling by logic tree





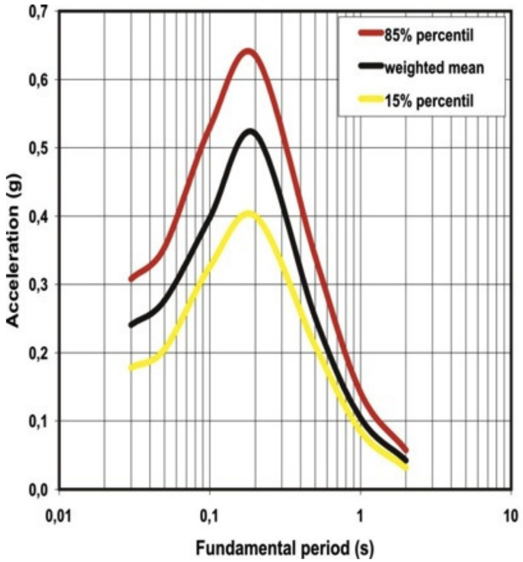


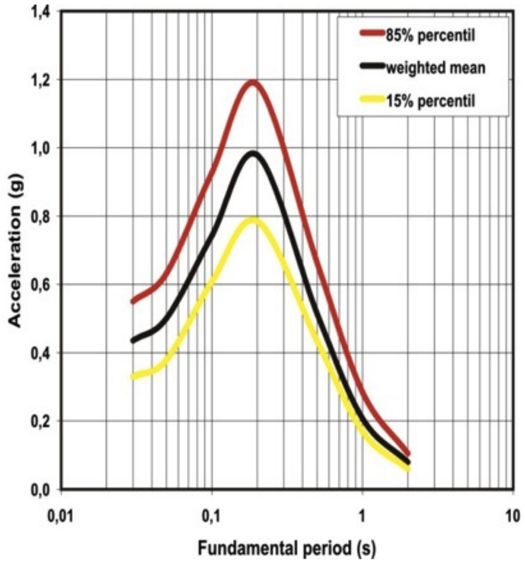
Seismic hazard curves along logic tree branches and "outcrop" UHRS

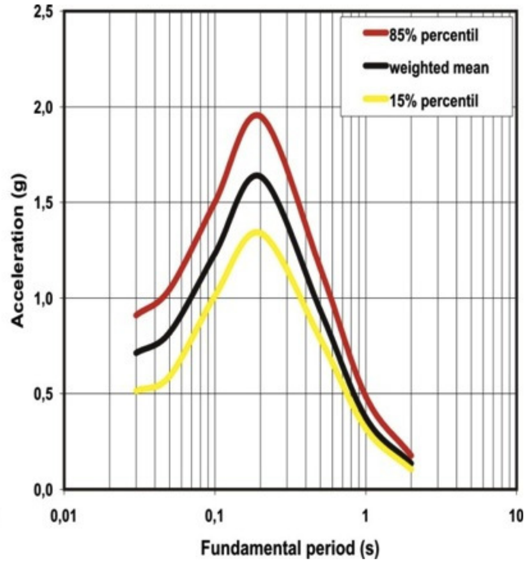
Thick black line is the weighted mean, yellow and red show 15% and 85% confidence levels.

Uniform Hazard Bedrock Response Spectrum (UHRS) for 10.000, 100.000 and 1.000.000 years.

Thick black line is the weighted mean, yellow and red show 15% and 85% confidence levels.







Summary of the program

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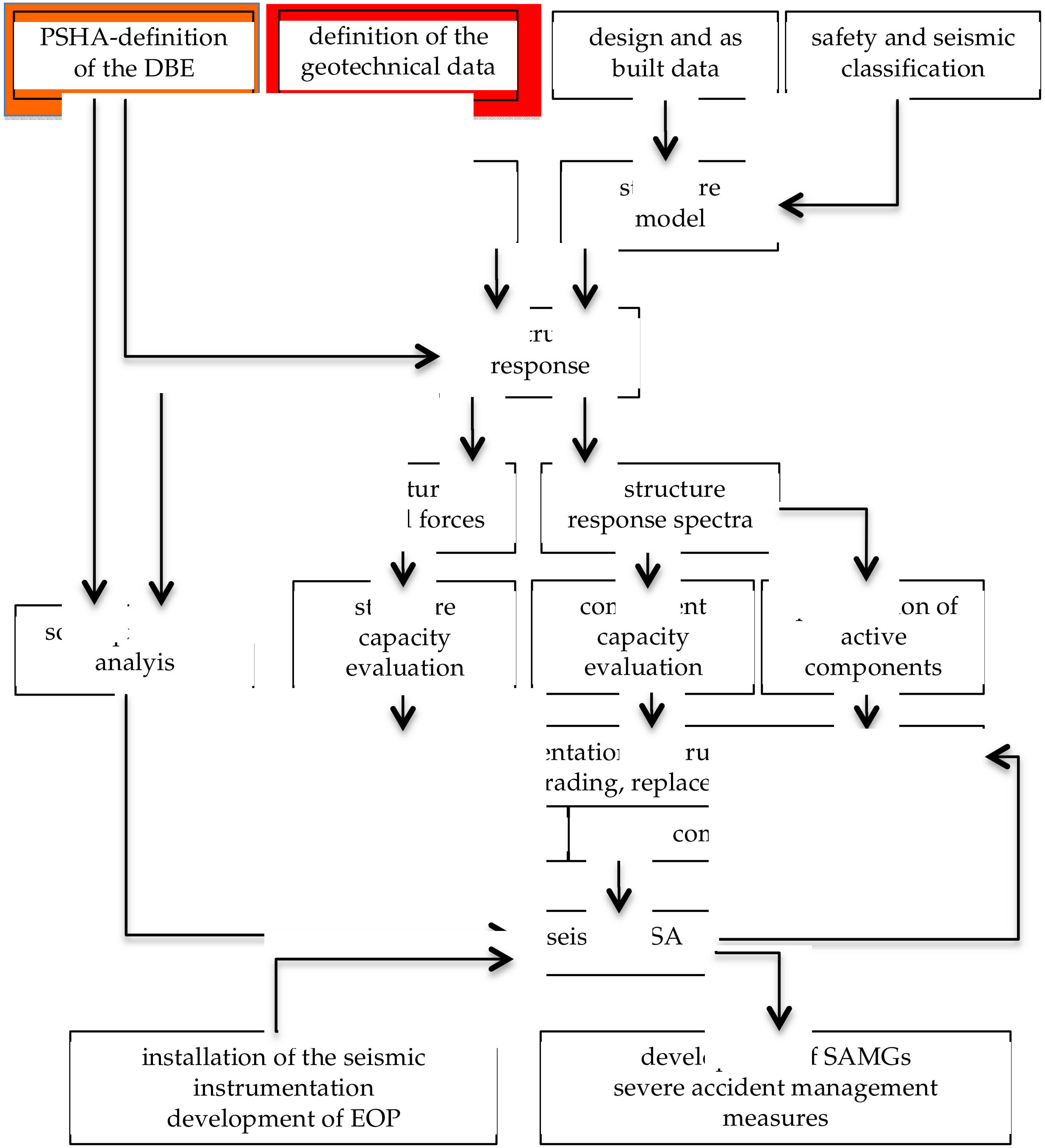
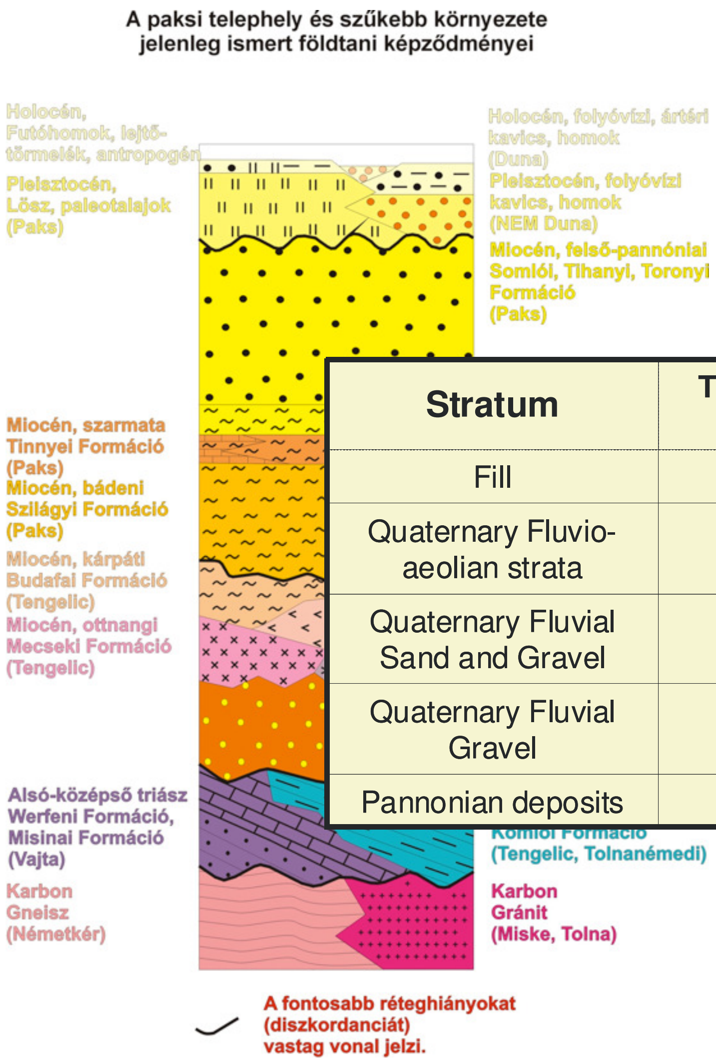
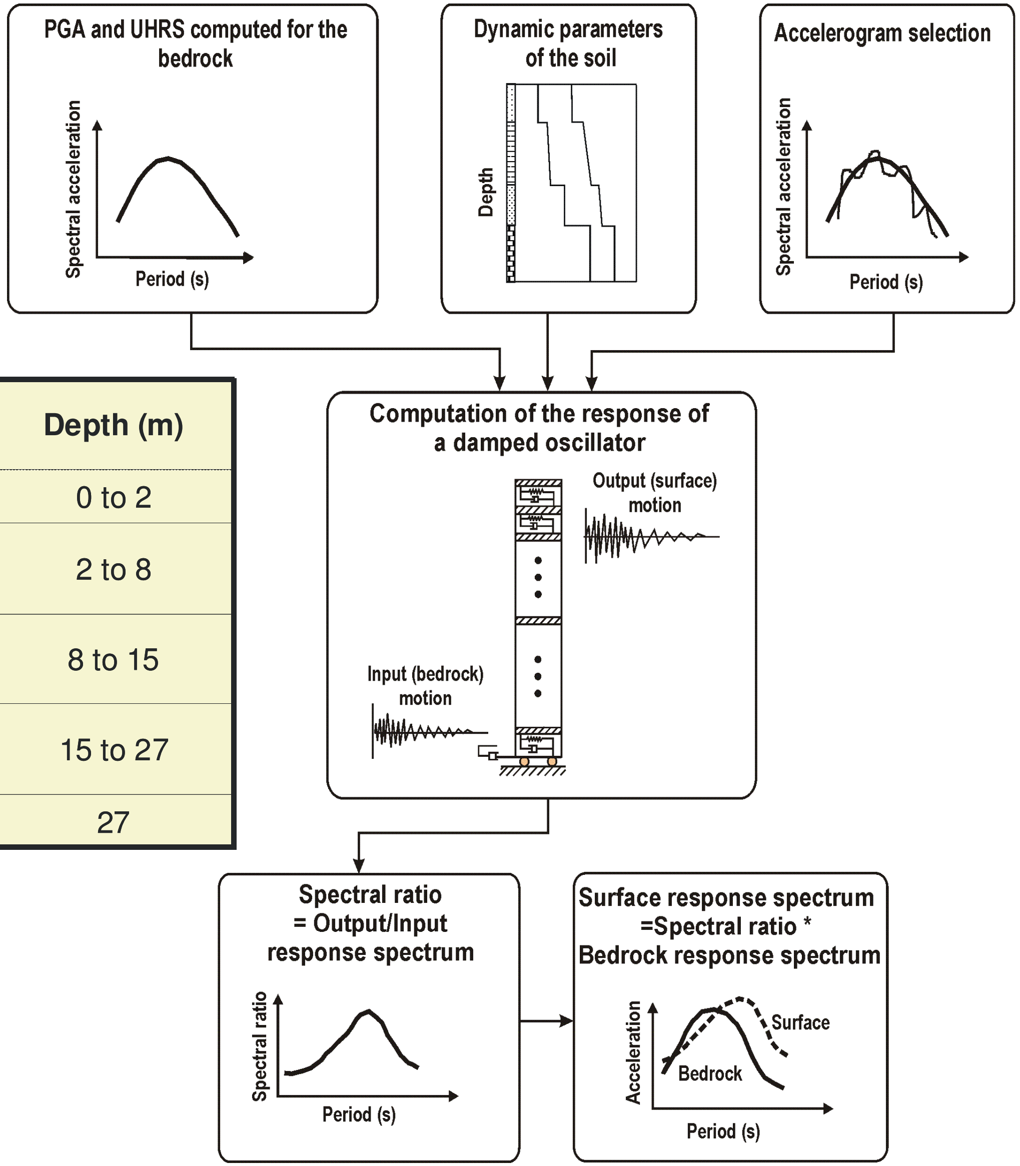


Site response analysis



Stratum	Thickness (m)	Depth (m)
Fill	2	0 to 2
Quaternary Fluvio-aeolian strata	6	2 to 8
Quaternary Fluvial Sand and Gravel	7	8 to 15
Quaternary Fluvial Gravel	12	15 to 27
Pannonian deposits		27

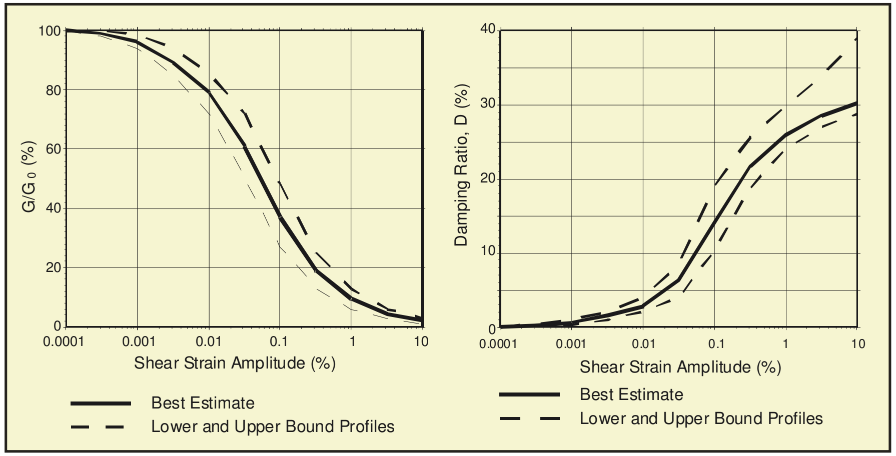


Input parameters – soil properties

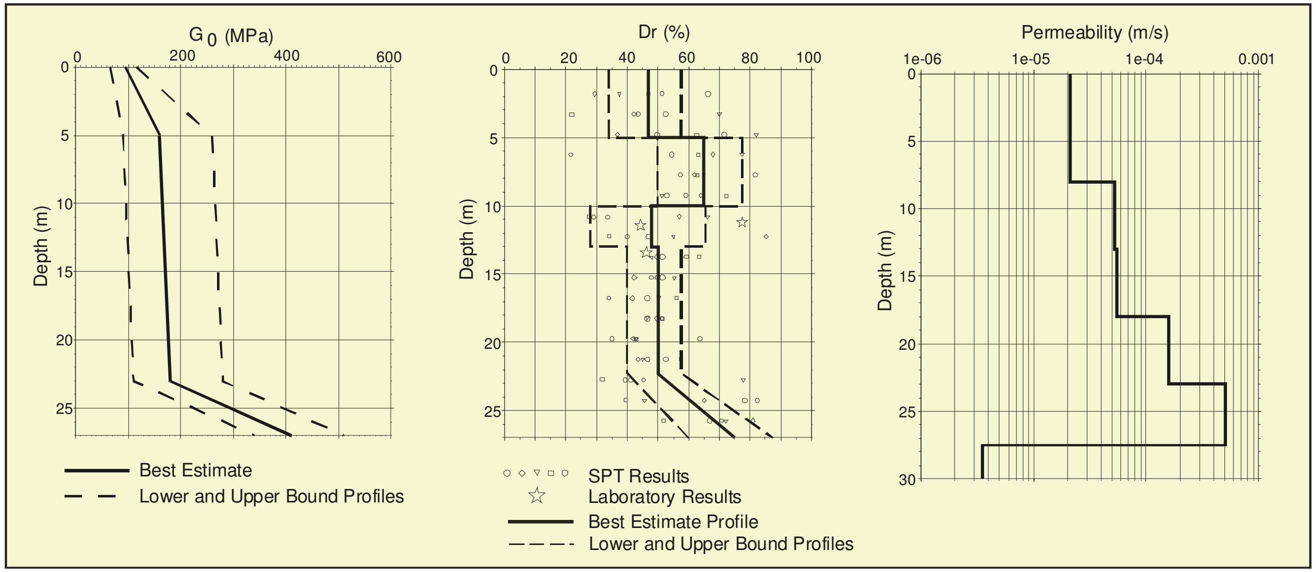
Stratum	Thickness (m)	Depth (m)
Fill	2	0 to 2
Quaternary Fluvio-aeolian strata	6	2 to 8
Quaternary Fluvial Sand and Gravel	7	8 to 15
Quaternary Fluvial Gravel	12	15 to 27
Pannonian deposits		27

Soil parameters

Depth (m)	Density (kg/m³)
0-8	1900
8-18	2000
15-17	2100

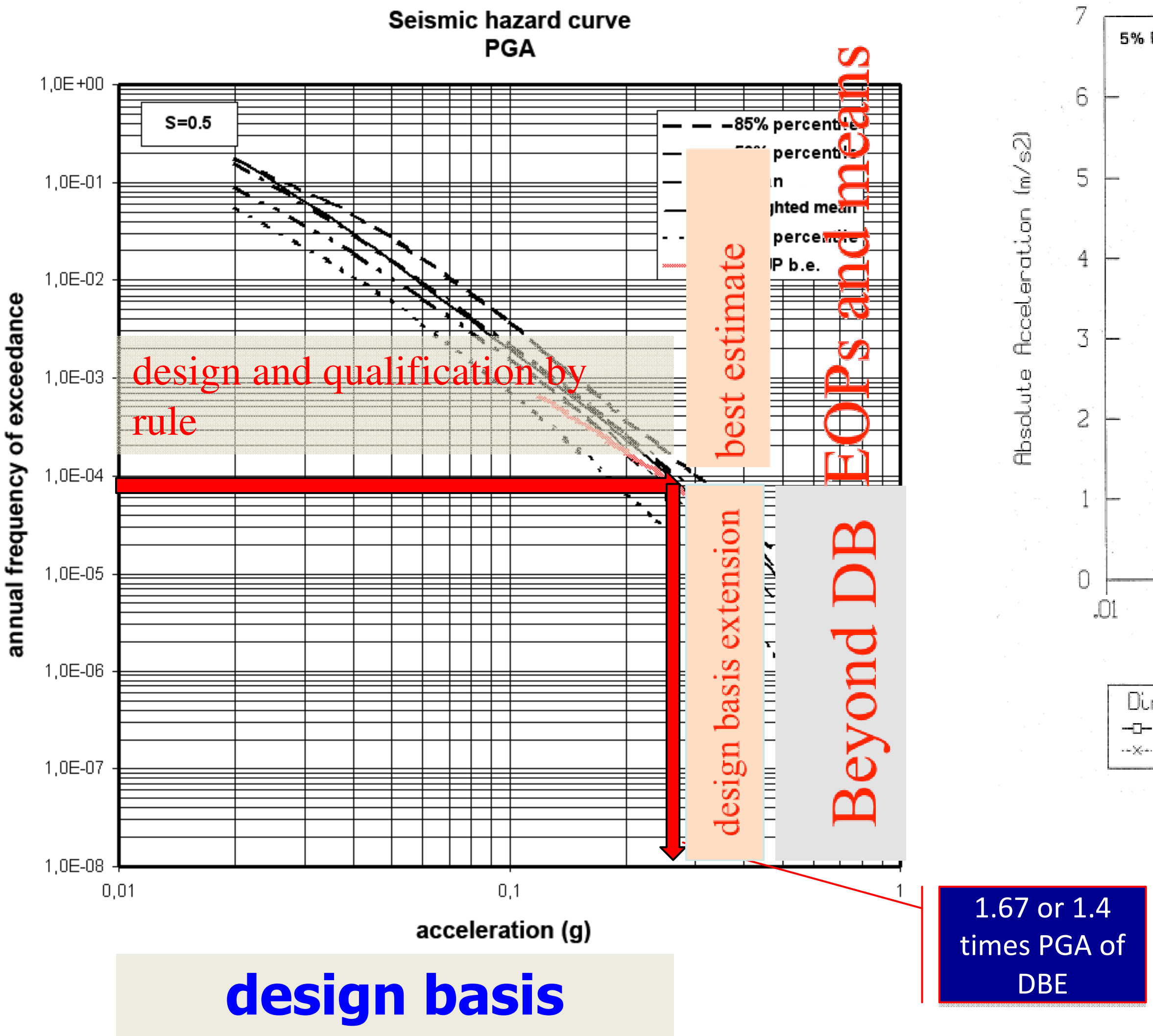


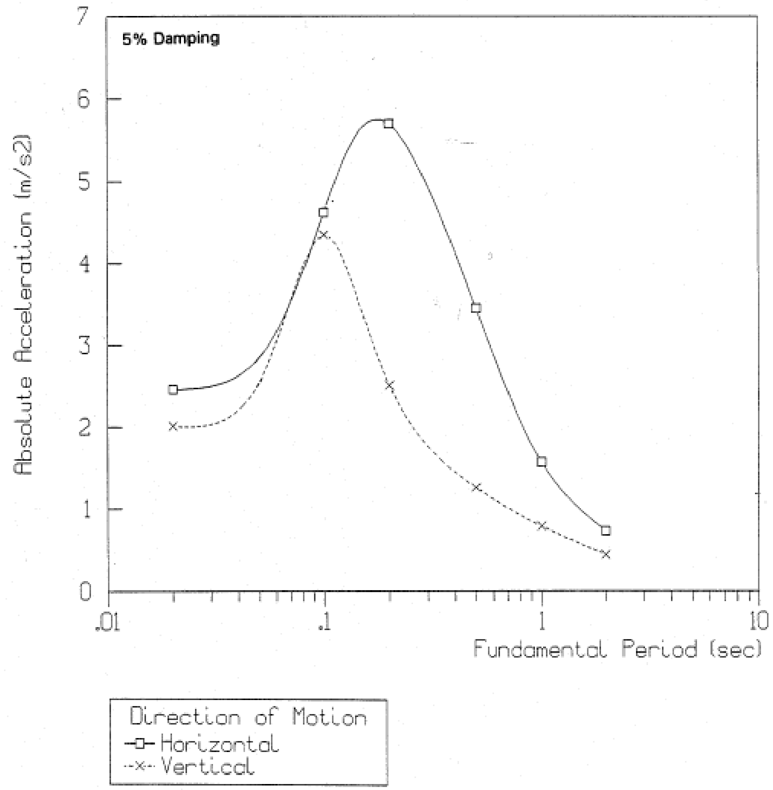
Shear modulus degradation and damping curves



Soil parameter distributions versus depth

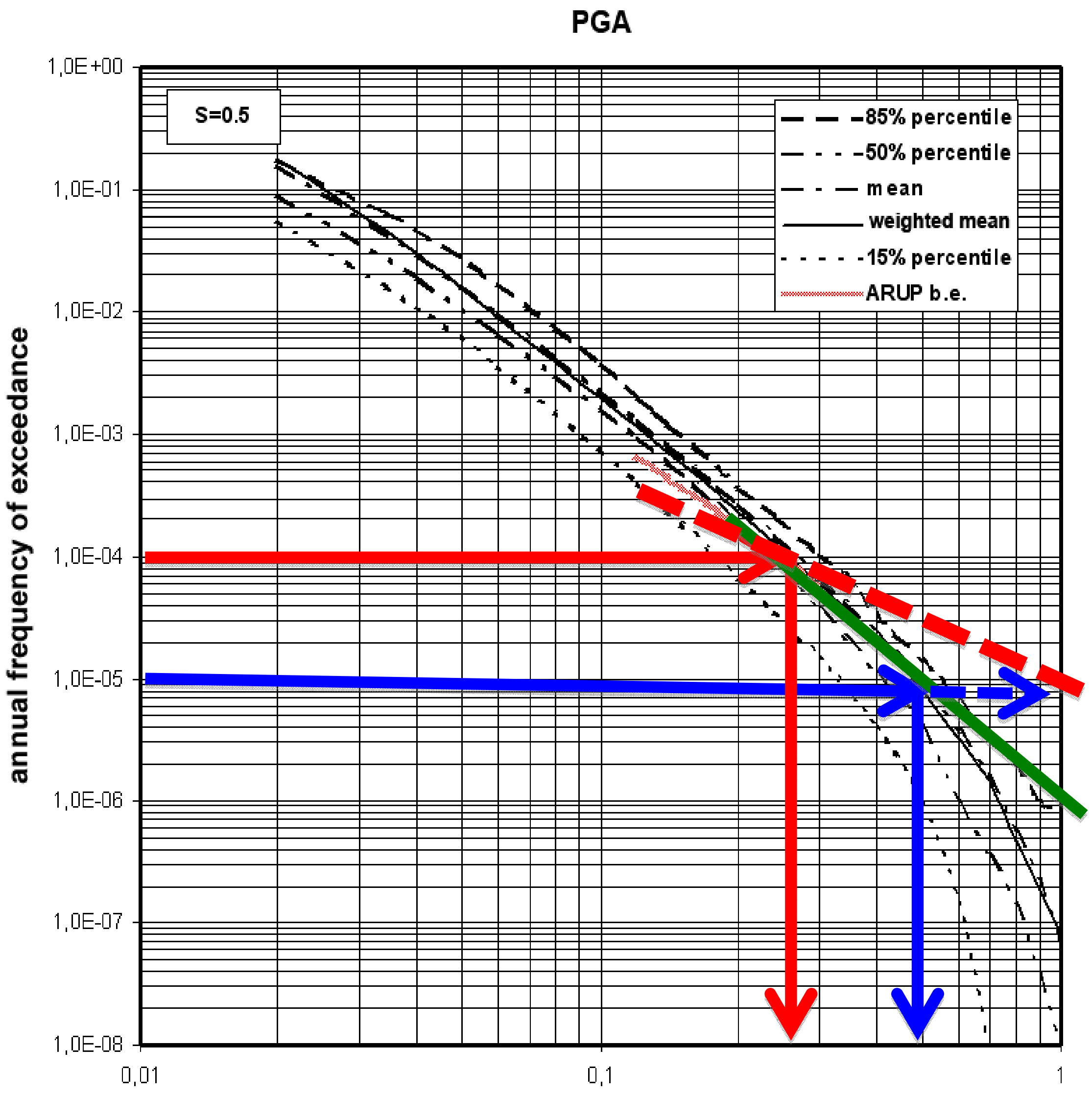
Design Basis Earthquake





Avoiding cliff-edge effect

Design basis response spectra have to be developed modifying the Ground Motion Response Spectra in accordance to ASCE/SEI 43-05 and Regulatory Guide 1.208 2007



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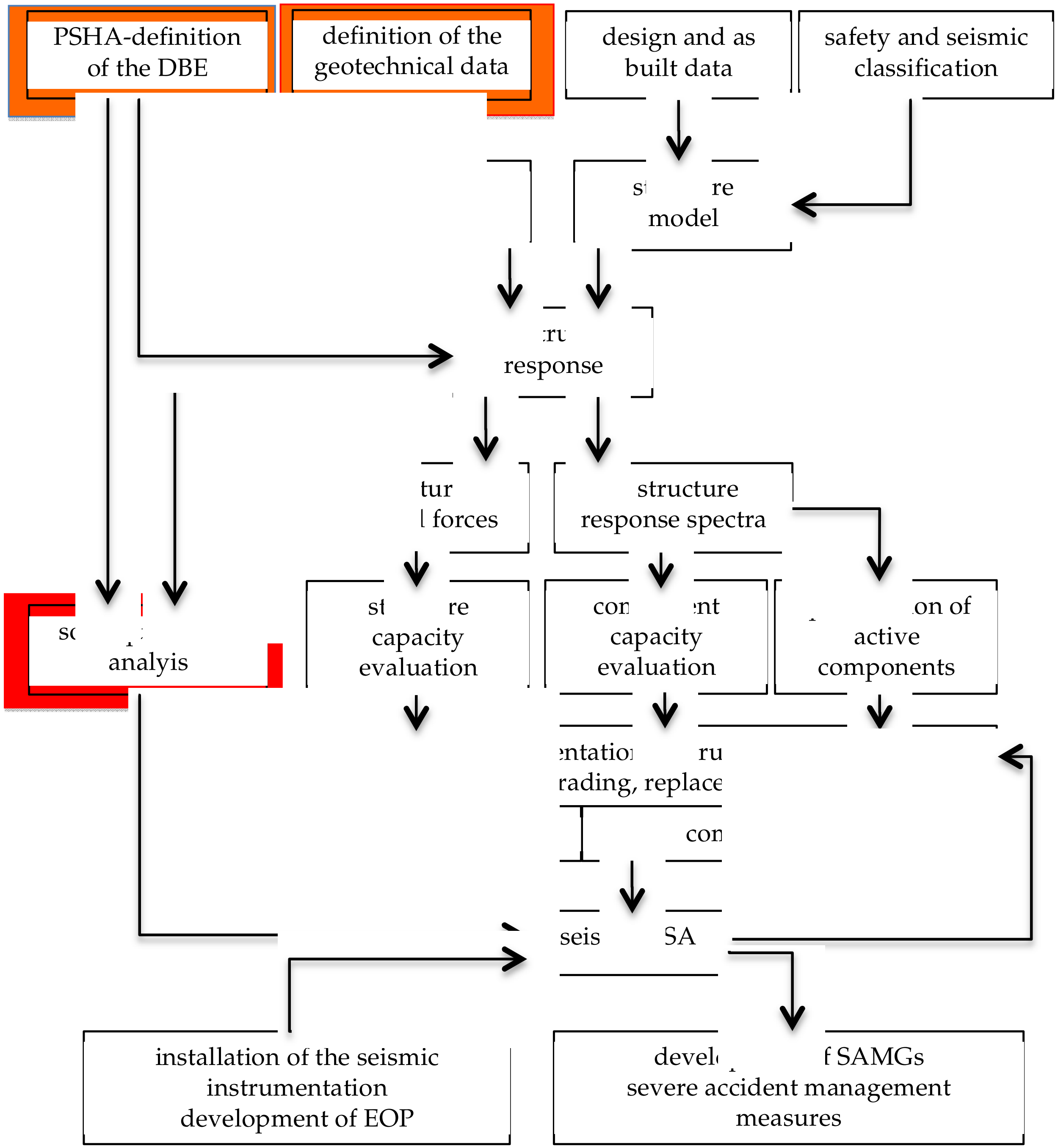


Site response – liquefaction hazard

- 1995-1996 probabilistic assessment of the liquefaction hazard, return period 14000-18000 years in a soil layer at ≈15m depth, consequently the liquefaction is not part of the design base (10-4/a criterion)
- Seismic PSA (different model for liquefaction as before) high contribution to the CDF, dominating beyond design base event. The issue was already recognized in the 2nd PSR and further actions are identified in TSR.

Margin to liquefaction can be defined as

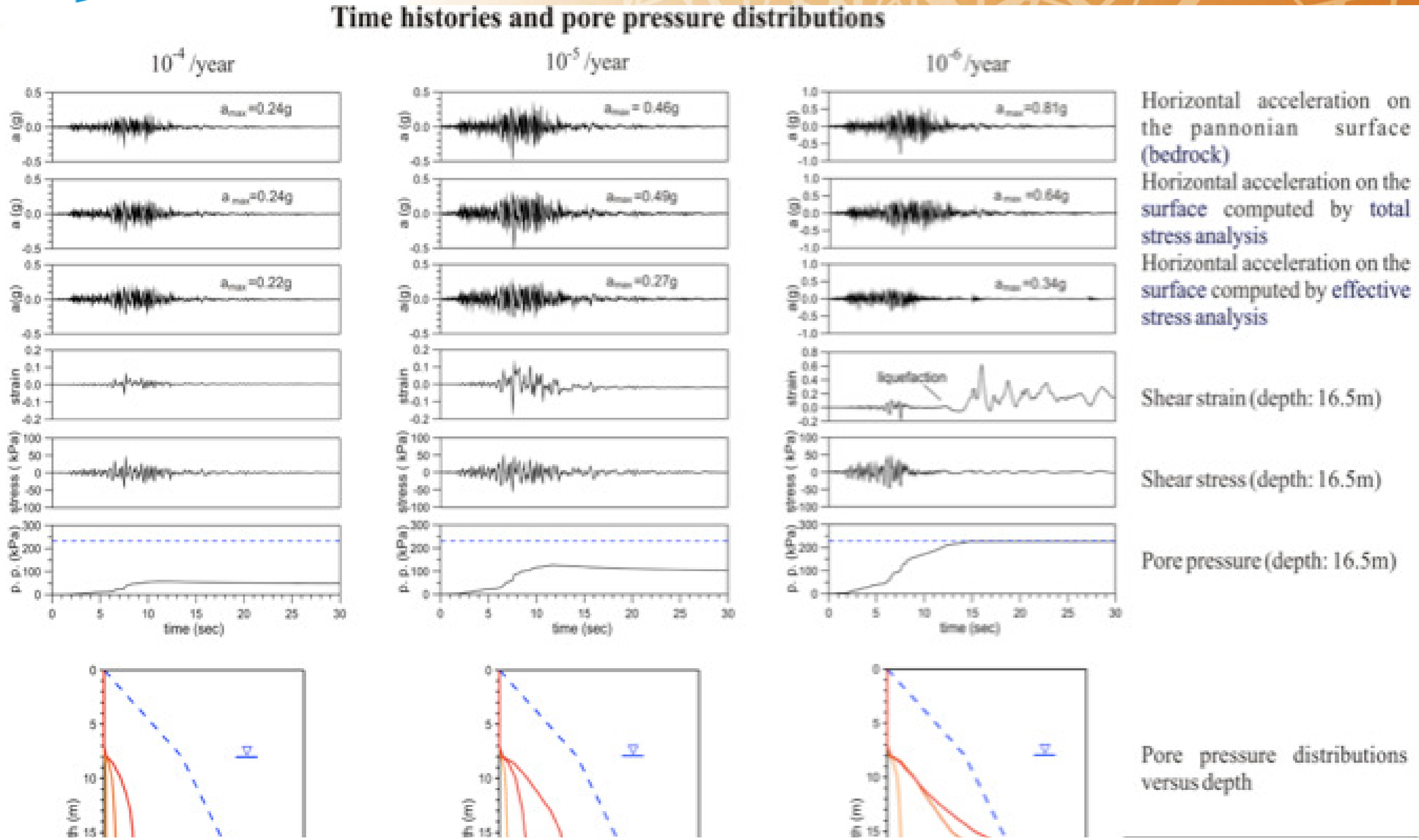
$$\mathbf{FS_{liq} = CRR/CSR}$$

where CRR is the cyclic resistance ration and the CSR is cyclic stress ratio (Reg. Guide 1.198).

Depending on the method used the value of safety factor varies in rather wide range.

For Paks site, several methodologies have been used: Seed and Idriss (1971) (10% margin only), as well as the effective stress method, which are much less conservative and gave larger margin.

Site response - Liquefaction hazard summary



Gyori E, Toth L, Monus P, Zsiros T, Katona T, Site Effect Estimations with Nonlinear Effective Stress Method at Paks Npp, Hungary. In: EGS XXVII General Assembly. Nice, France, 2002.04.21-2002.04.26. *Paper 4033.*

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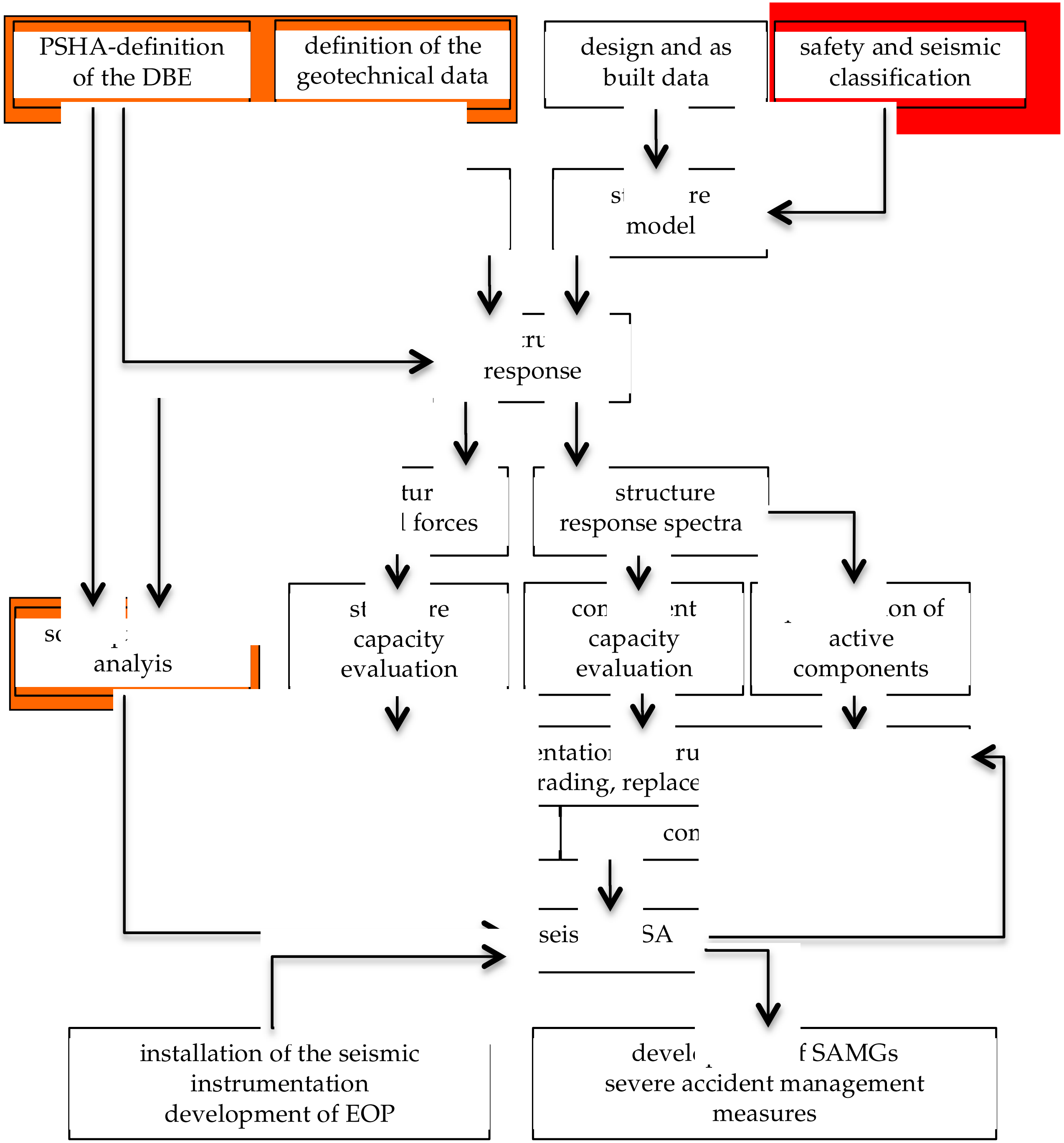

Seismic safety concept, seismic safety classification

Aim: to ensure the basic safety function in case of DBE (shut-down and cooling of reactor (spent-fuel-pool), and containment)

Minimum requirement: success path for bringing the reactor to stable cooled condition + back-up (diverse)

minimum configuration

Paks NPP case: design base reconstitution, i.e. al safety related systems, structures and components are within the scope

IAEA SAFETY STANDARDS SERIES No. SSR-2/1 SAFETY OF NUCLEAR POWER PLANTS: DESIGN

5.20. The design shall be such as to ensure that items important to safety are capable of withstanding the effects of external events considered in the design, and if not, other features such as passive barriers shall be provided to protect the plant and to ensure that the required safety function will be performed.

5.21. The seismic design of the plant shall provide for a sufficient safety margin to protect against seismic events and to avoid cliff edge effects (see footnote 5).

5.22. For multiple unit plant sites, the design shall take due account of the

potential for specific hazards giving rise to simultaneous impacts on several units on the site.

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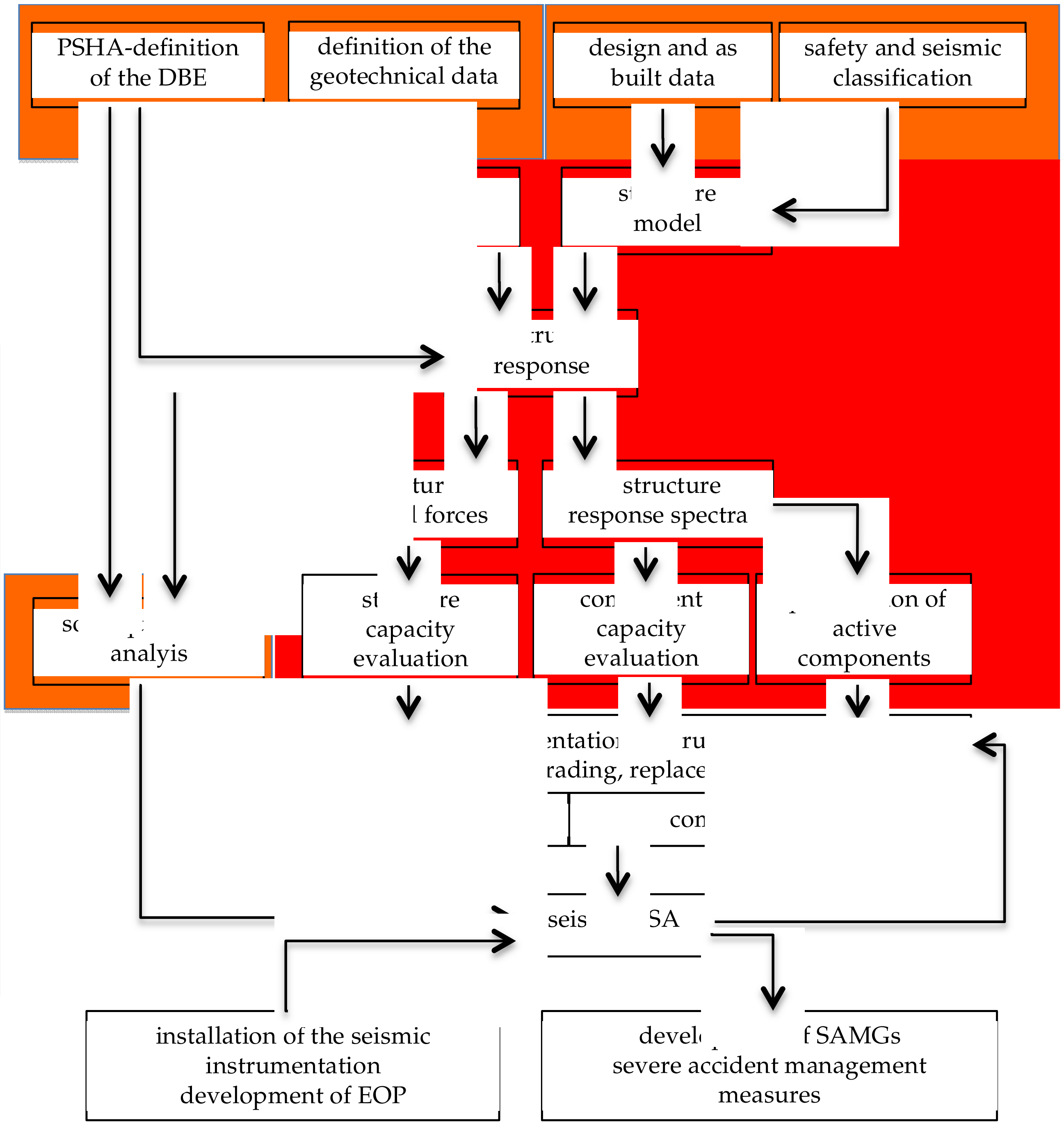
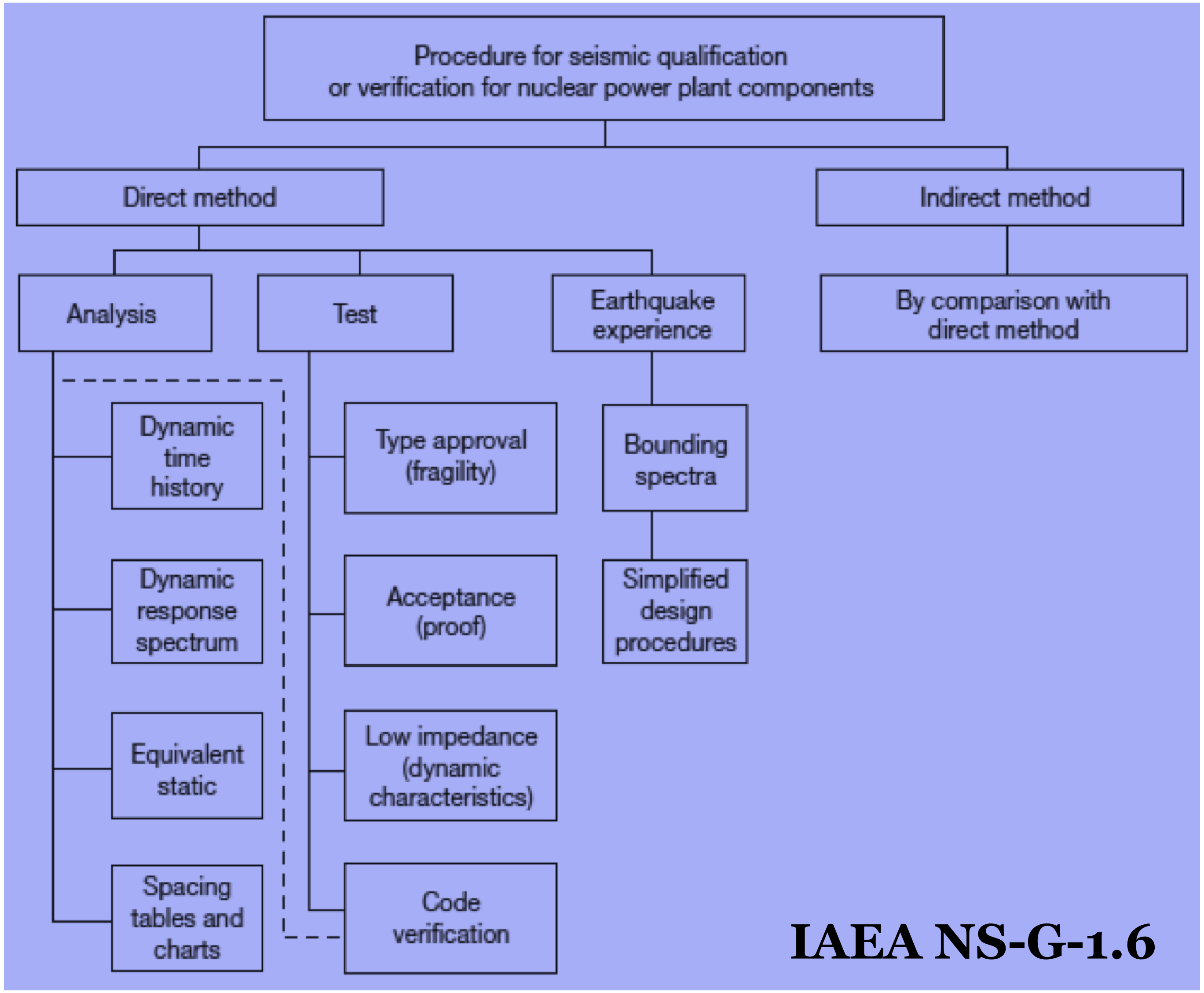


Seismic qualification of NPP components

- Analysis for load and pressure bearing structures and components, earth-structures, as per standards;
- Test (preferable) – Regulatory Guide 1.139;
- Experience based qualification (SQUG-GIP)

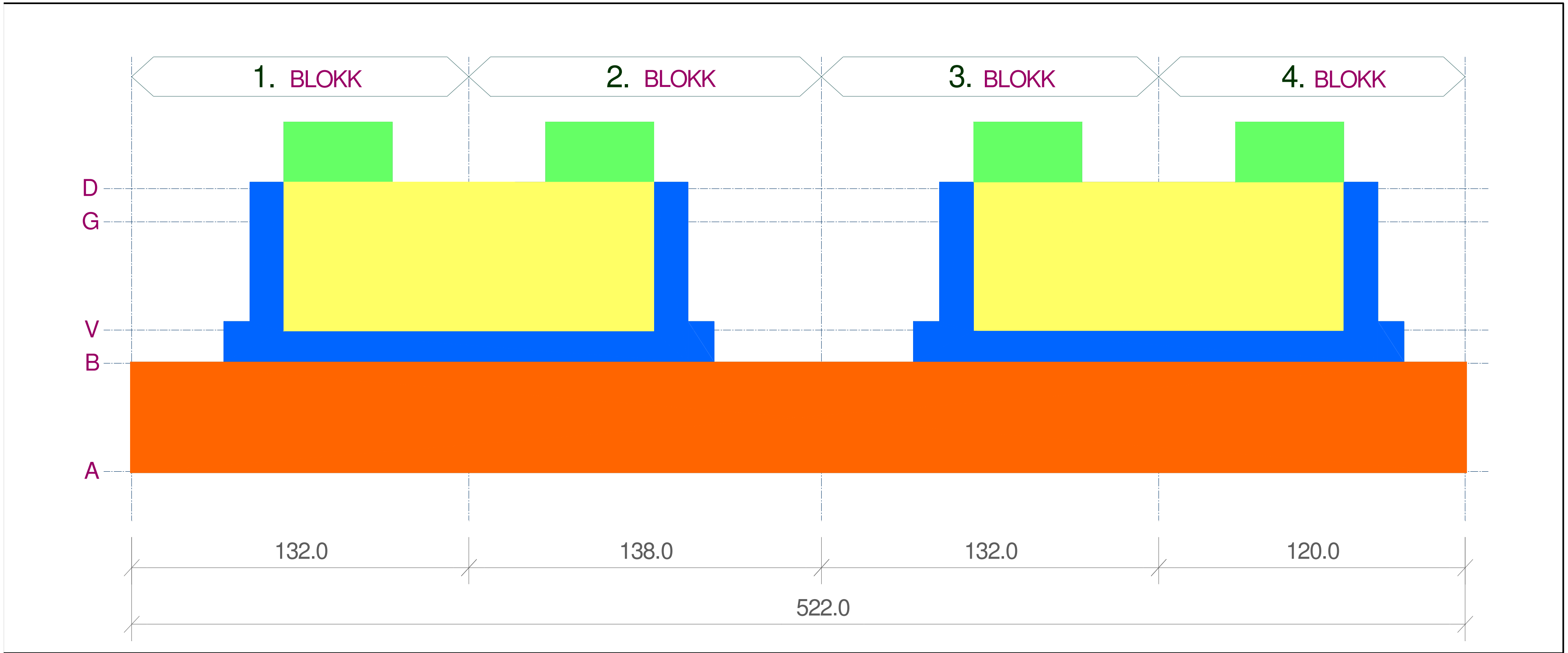
IAEA NS-G-2.13

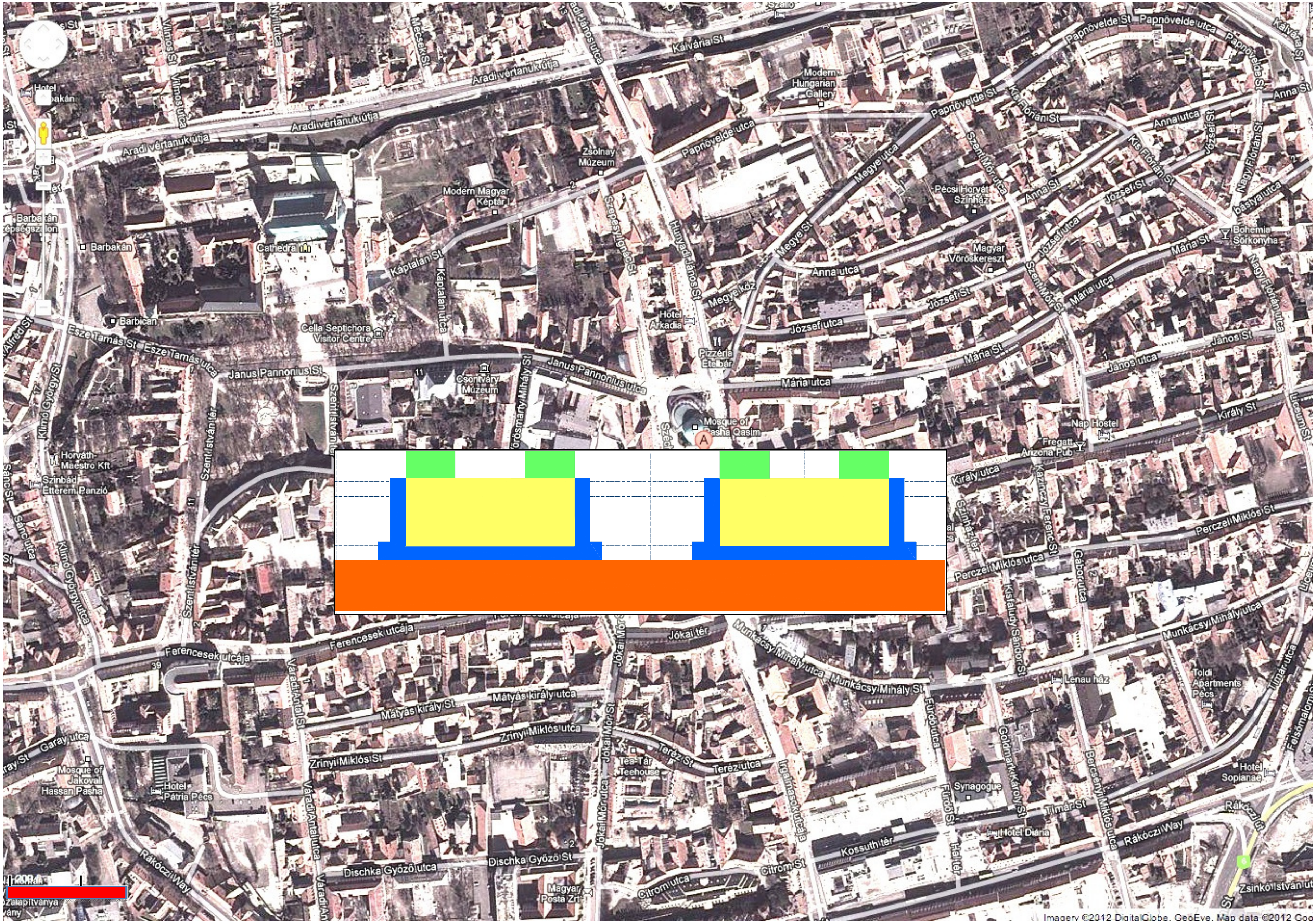


IAEA NS-G-1.6

Seismic evaluation and upgrading

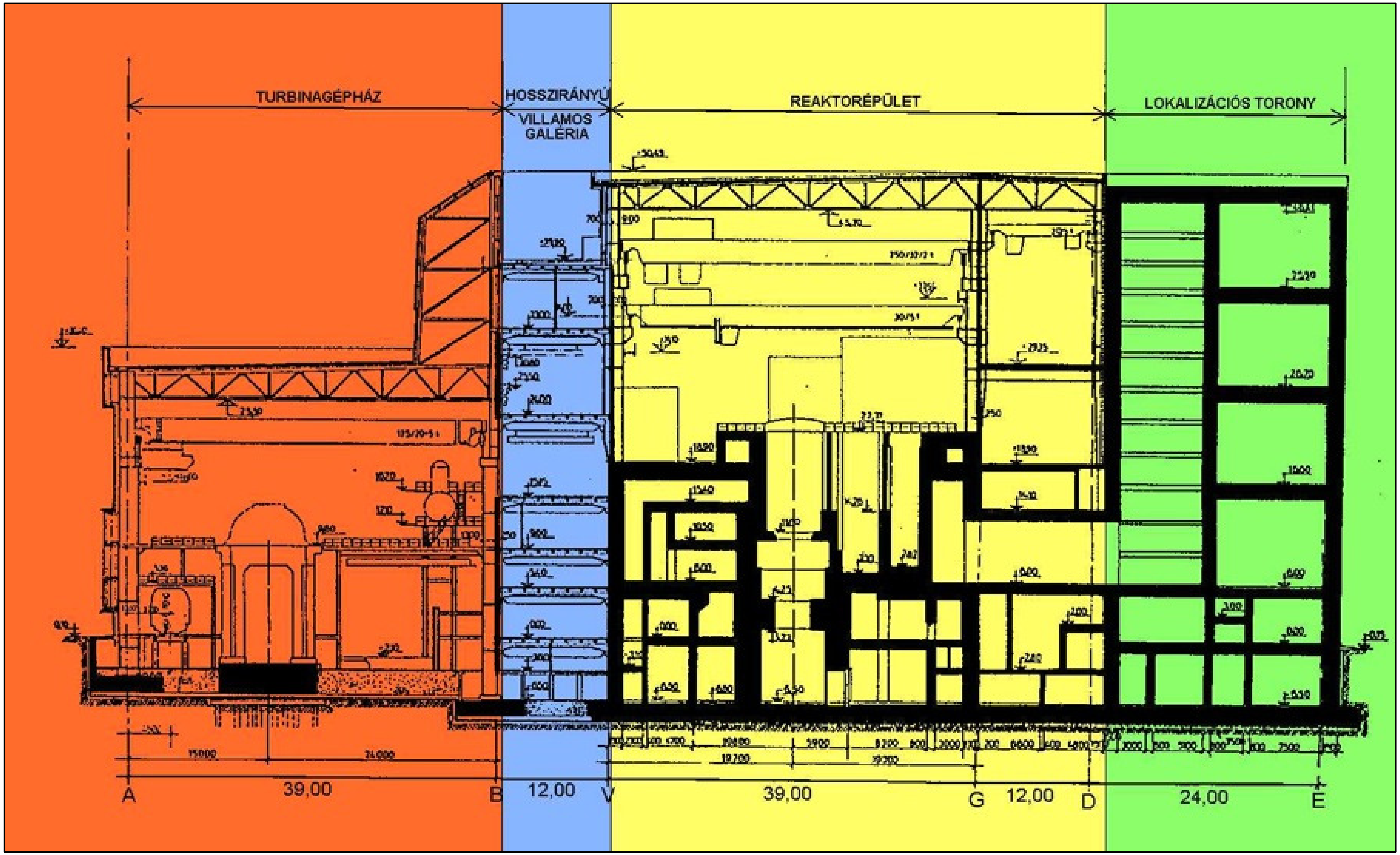
Main building complex





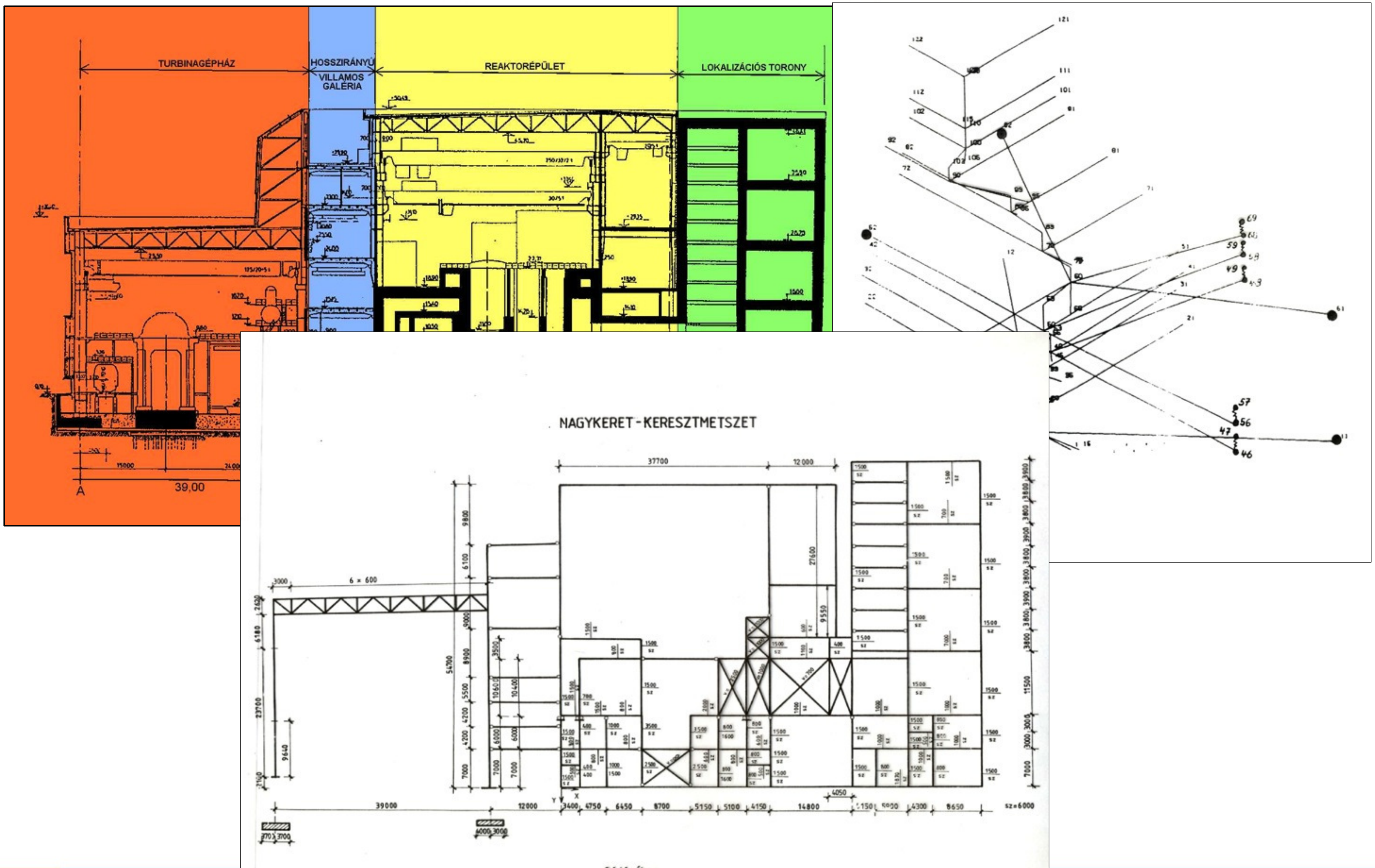
Kálvária St
Aradi vértanuk útja
Papnövelde utca
Papnövelde St
Modern Hungarian Gallery
Zsolnay Múzeum
Modern Magyar Képtár
Cathedral
Barbakán
Barbican
Káptalan St
Káptalan utca
Megye utca
Megye St
Pécsi Horvát Színház
Anna utca
Anna St
József utca
József St
Mária utca
Mária St
János St
Bohemia Sörkonyha
Magyar Vöröskereszt
Hotel Arkádia
Pizzéria Étterem
Cella Septichora Visitor Centre
Janus Pannonius St
Janus Pannonius utca
Eszé Tamás St
Eszé Tamás utca
Csontváry Múzeum
Szent István tér
Mosque of Pasha Qasim
Király St
Király utca
Nap Hostel
Fregatt Arizona Pub
Horváth Maestro Kft
Szinbád Étterem Panzió
Klimó György utca
Perczel Miklós utca
Perczel Miklós St
Ferencesek utcája
Jókai tér
Munkácsy Mihály utca
Munkácsy Mihály St
Lenau ház
Toldi Apartments Pécs
Mátyás király utca
Mátyás király St
Zrínyi Miklós utca
Zrínyi Miklós St
Garay utca
Mosque of Jakovali Hassan Pasha
Hotel Pátria Pécs
Tea Tár Teehouse
Teréz utca
Teréz St
Synagogue
Hotel Sopianae
Hotel Diána
Rákóczi Way
Kossuth tér
Citrom St
Citrom utca
Dischka Győző utca
Dischka Győző St
Magyar Posta Zrt
Váradi Antal utca
Zsinkó István u
Imagery ©2012 DigitalGlobe, GeoEye, Map data ©2012 Goo

E-W cross-section of the main building



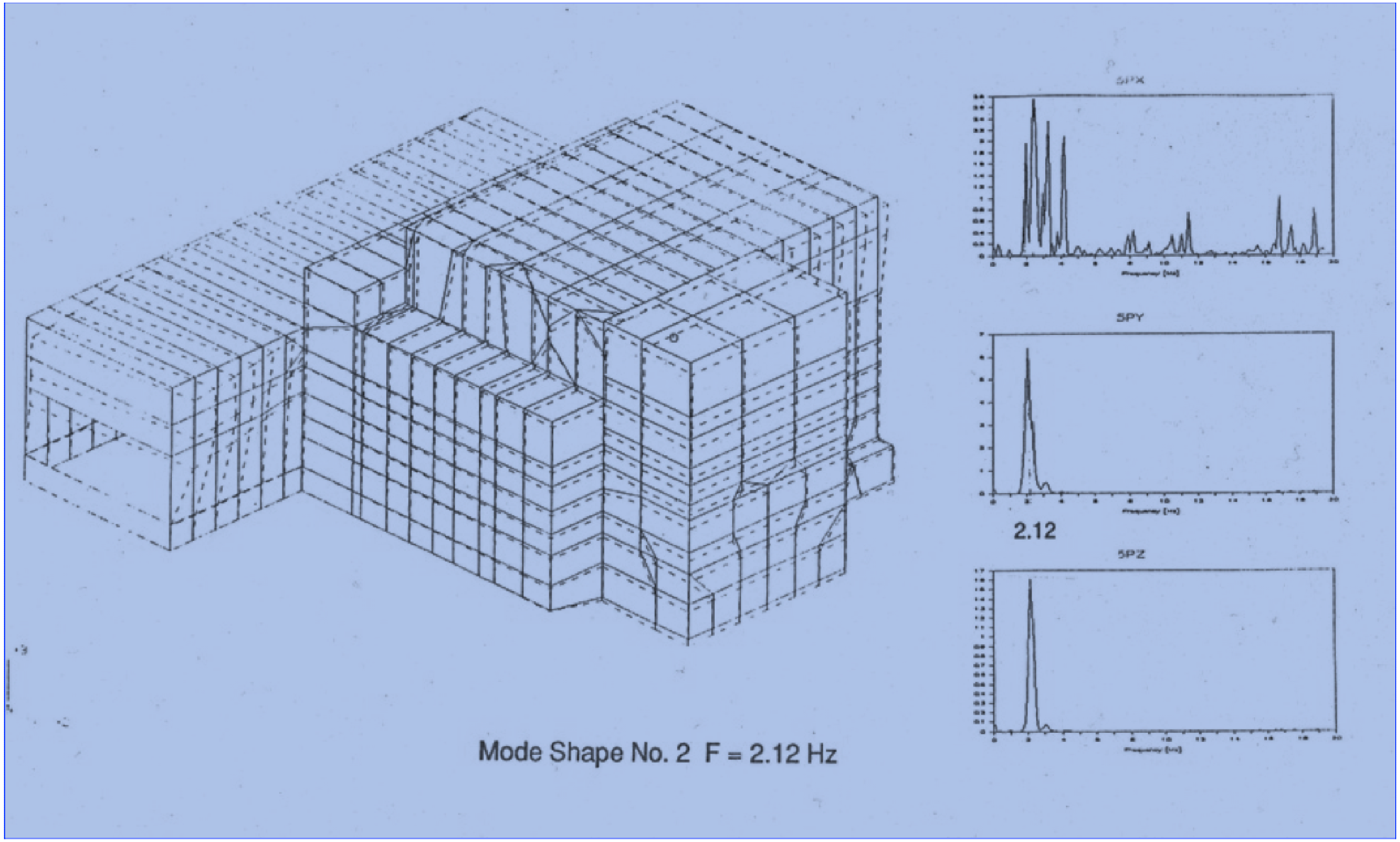

LOKOMO
A 351 NS

Analysis of mai building – modeling options



Experimental modal analysis

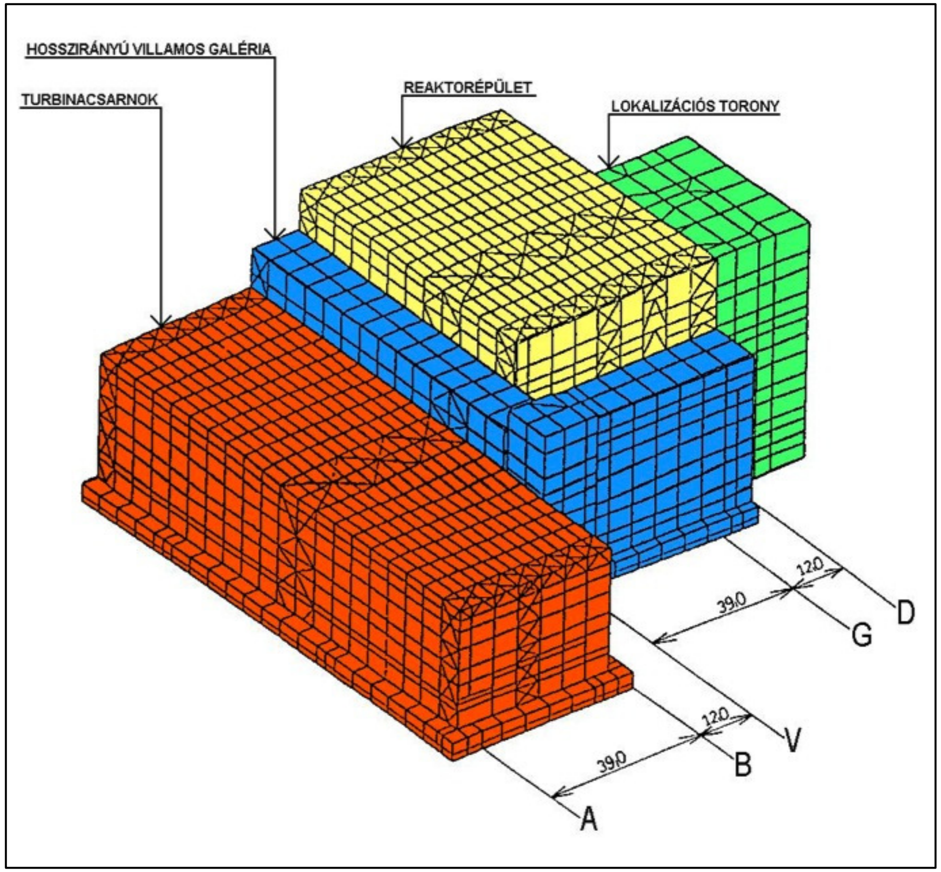
Blast-experiments

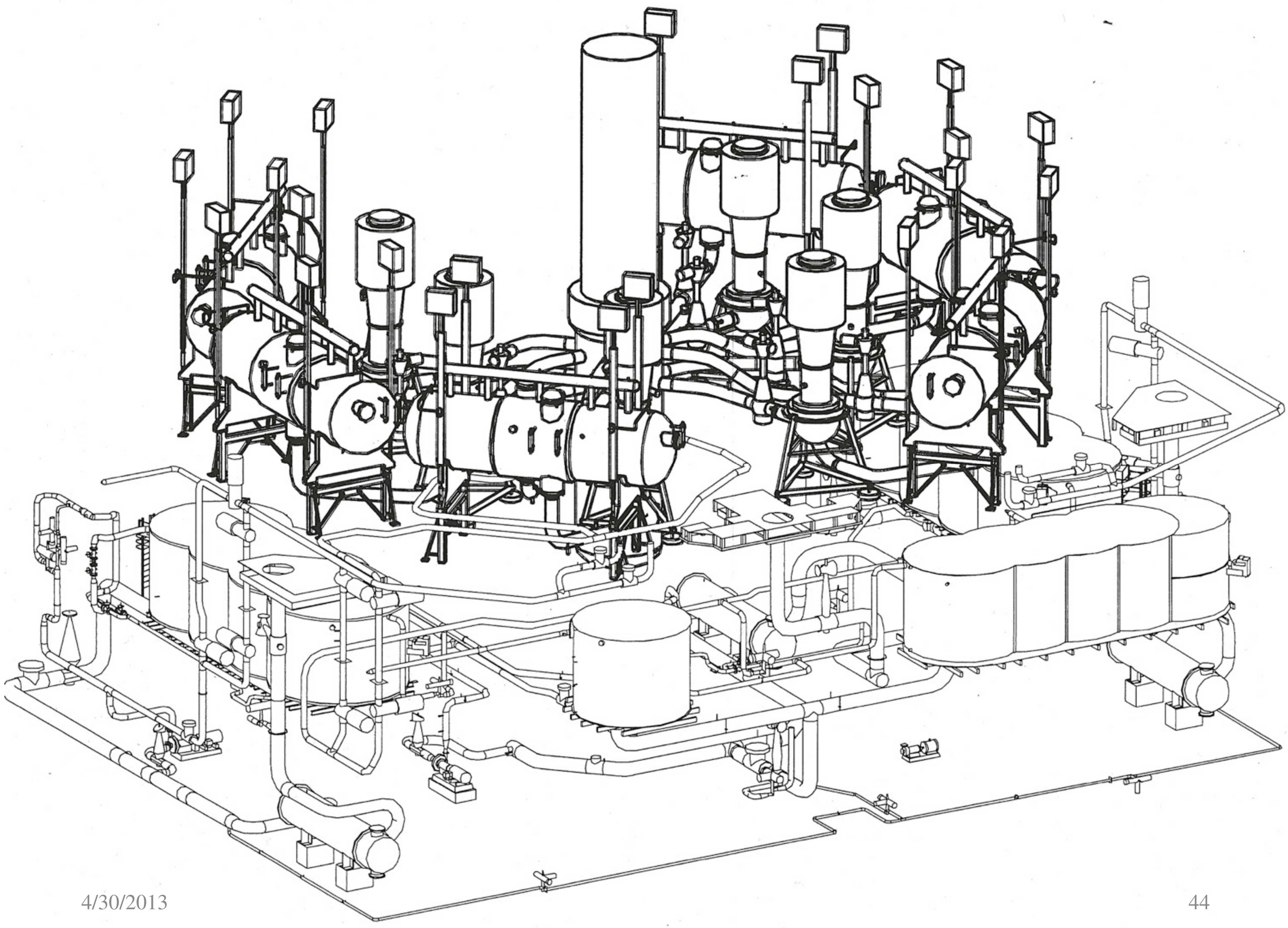


Mode Shape No. 2 F = 2.12 Hz

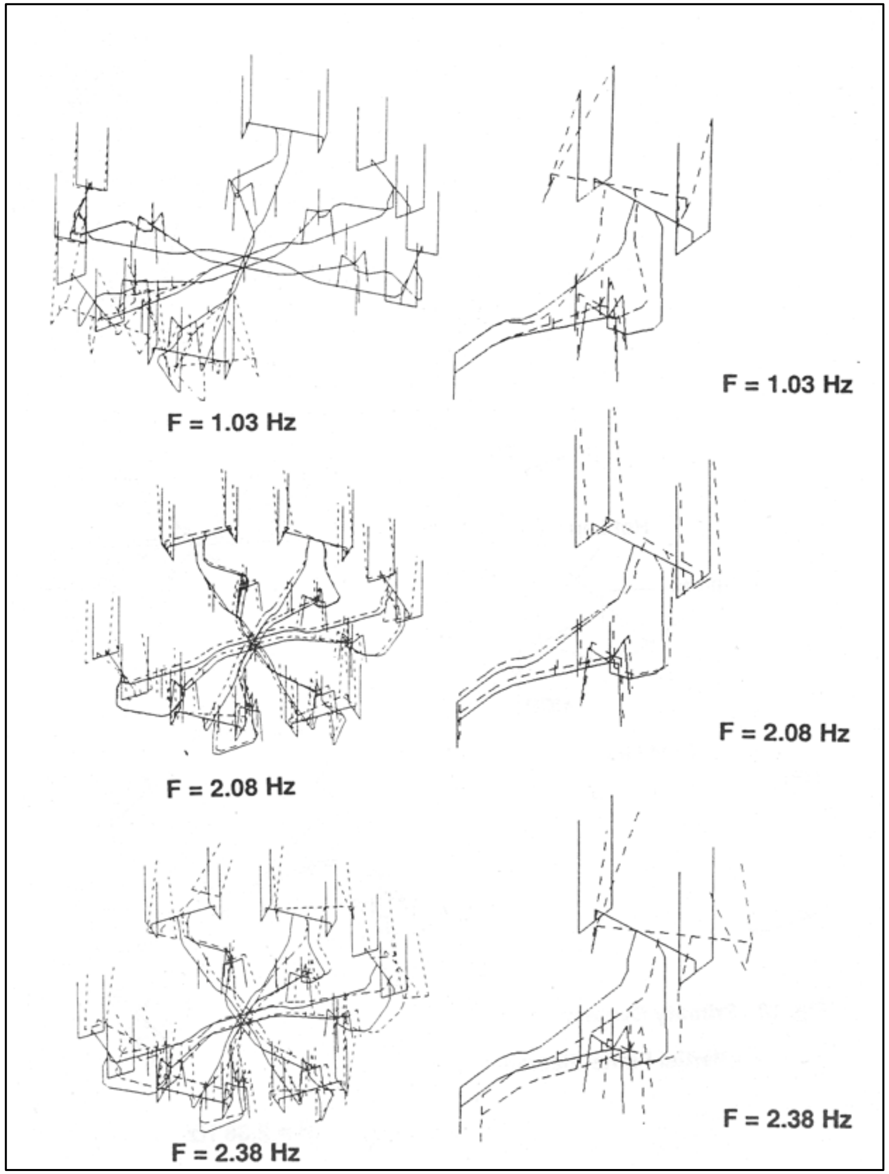
3-D model

- 3-D coupled model
- heterogeneous distribution of masses and stiffnesses merevségek
- SSI
- 28000 DOF
  - 4700 nodes
  - 5400 shell elements
  - 4600 rod elements
- nonstructural elements modelled as masses





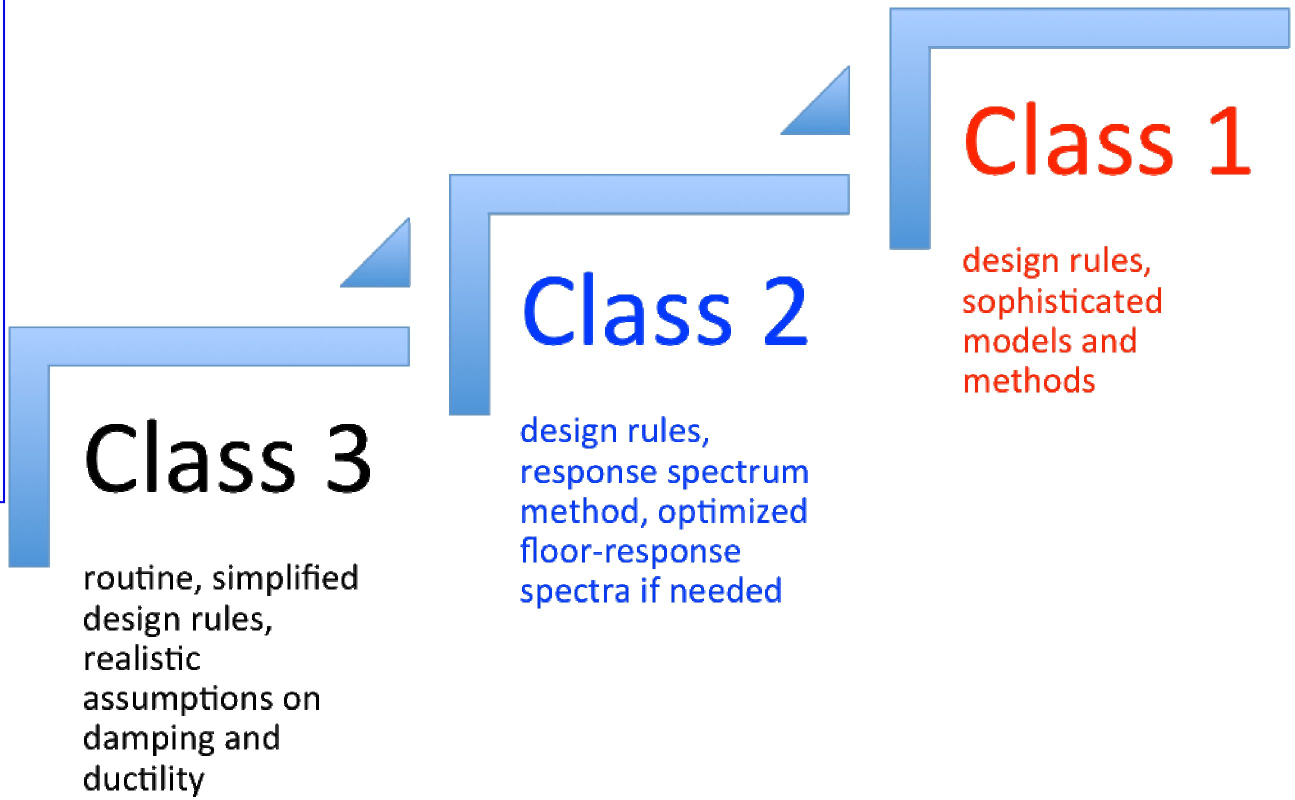
Experimental modal analysis of primary system



Graded approach for evaluation and qualification

Graded approach taking into account the requirements for design base reconstitution:

- ◆applied method of analysis
- ◆modelling of structures
- ◆assumptions : damping and ductility



Methods and assumptions

Load combinations	NOL+DBE	
Damping, ductility	Code values or realistic for repeated checking of outliers	
Structural models	Graded approach to the modelling: best estimate if applicable	
Floor response spectra	Conservative design floor response spectra. In specific case best estimate	
Material strength	Minimum values determined by standard	
Capacity evaluation	Design type evaluation	KTA, primary system and vital mechanical equipment and pipelines inside the confinement area
	Margin type evaluation	CDFM assumptions+ASME
	Simplified evaluation	Code based simplified procedures
Operability	GIP or GIP-VVER, if applicable, otherwise test	

Equipment	Item	Applicable standards
Passive equipment (tanks, pressure vessels, etc.)	Component body including internal parts	ASME BPVC Section III, Service level D KTA 3201/3211
	Supports	ASME BPVC Section III Subsection NF KTA 3205; Subsection according to Classes.
	Essential nozzles	ASME BPVC Section III, Service level D KTA 3201/3211
	Interactions	GIP, GIP-VVER
Active equipment	Operability	replacement (reactor protection system), tests, GIP, GIP-VVER
	Component body including internal parts	ASME BPVC Section III, Service level D KTA 3201/3211
	Supports	ASME BPVC Section III Subsection NF KTA 3205;
	Essential nozzles	ASME BPVC Section III, Service level D KTA 3201/3211
	Interactions	GIP, GIP-VVER
Pipelines	Pipelines	ASME BPVC Section III, Service level D KTA 3201/3211
	Supports	ASME BPVC Section III Subsection NF KTA 3205;
	Interactions	GIP, GIP-VVER

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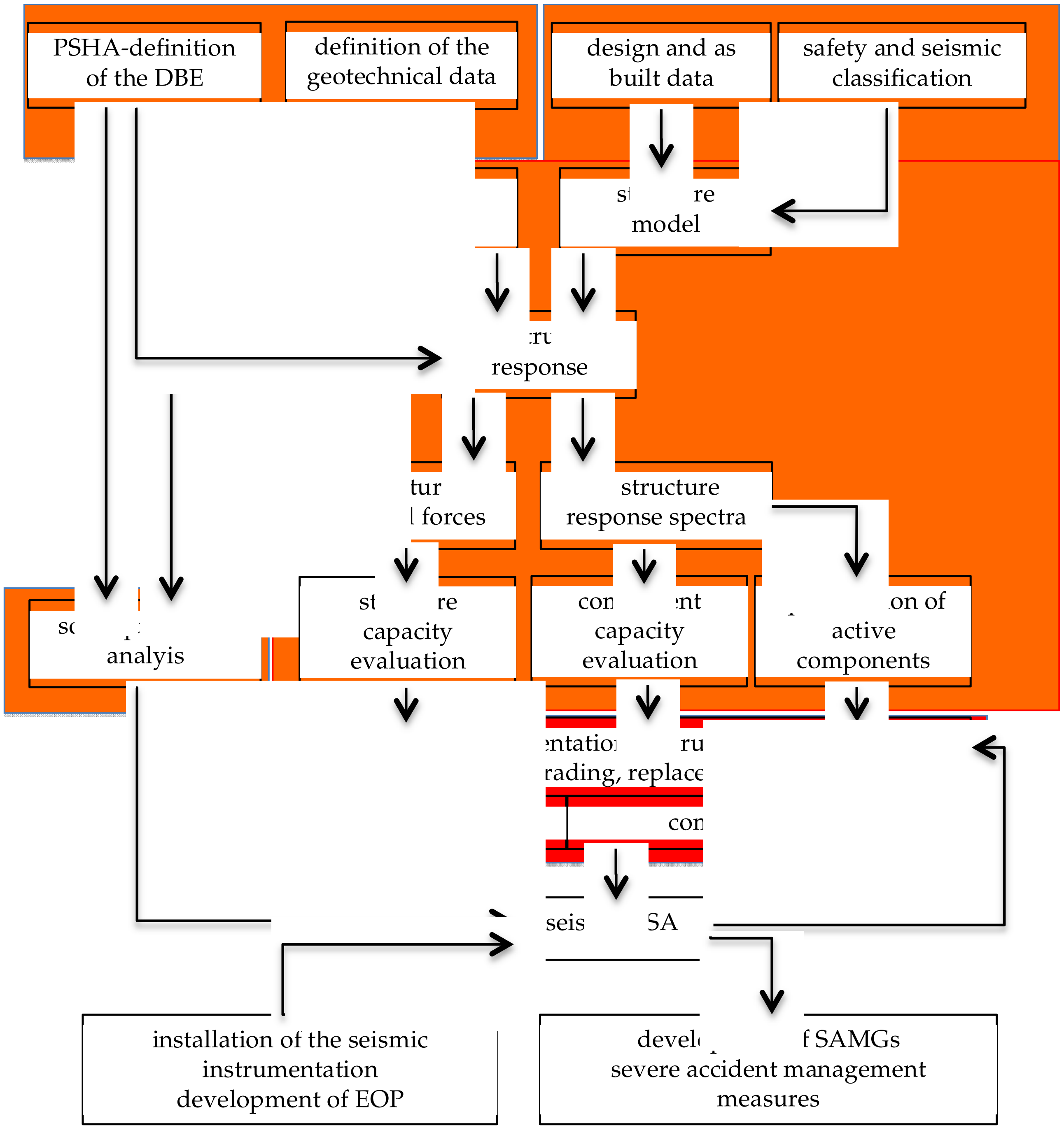
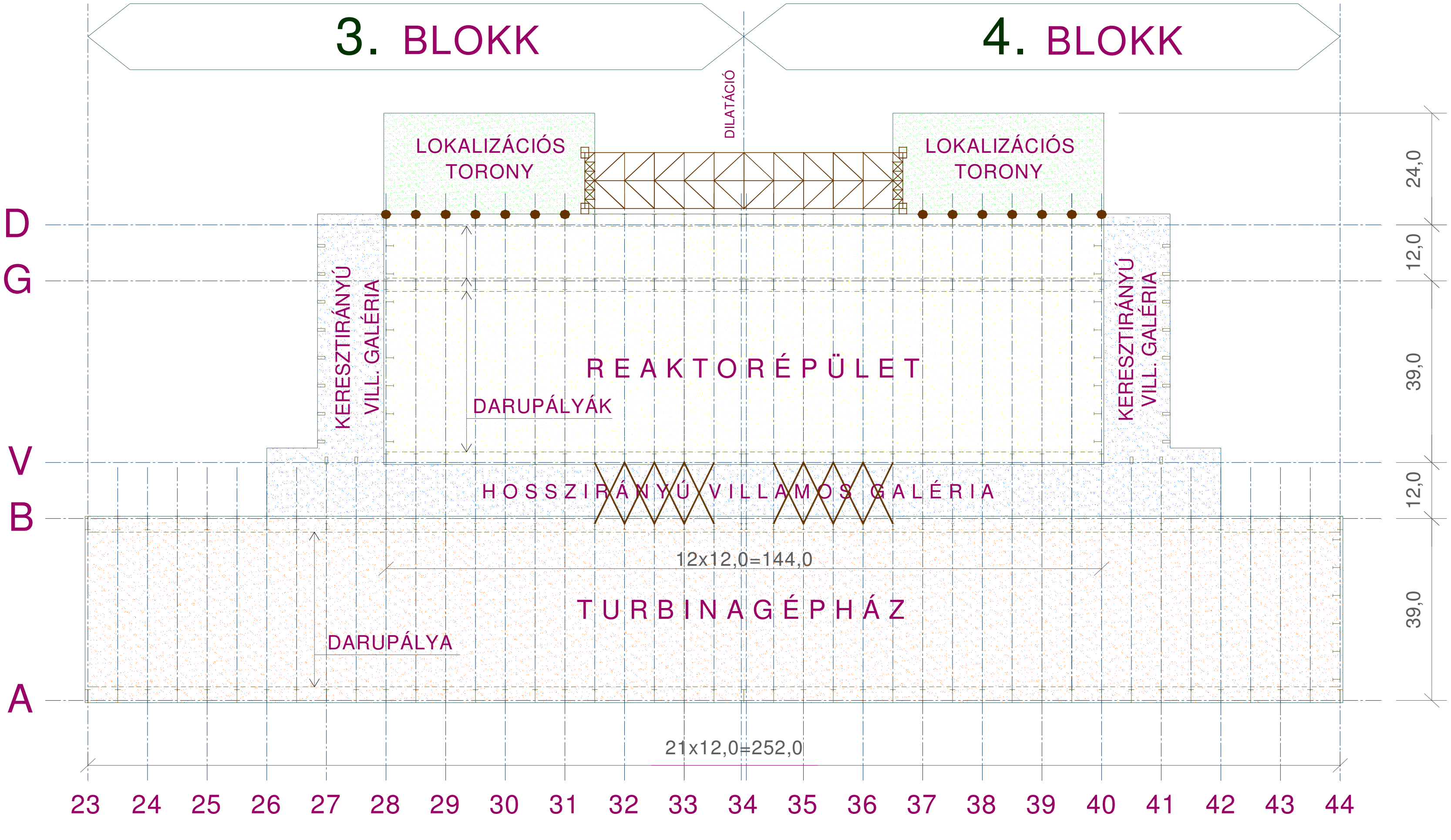
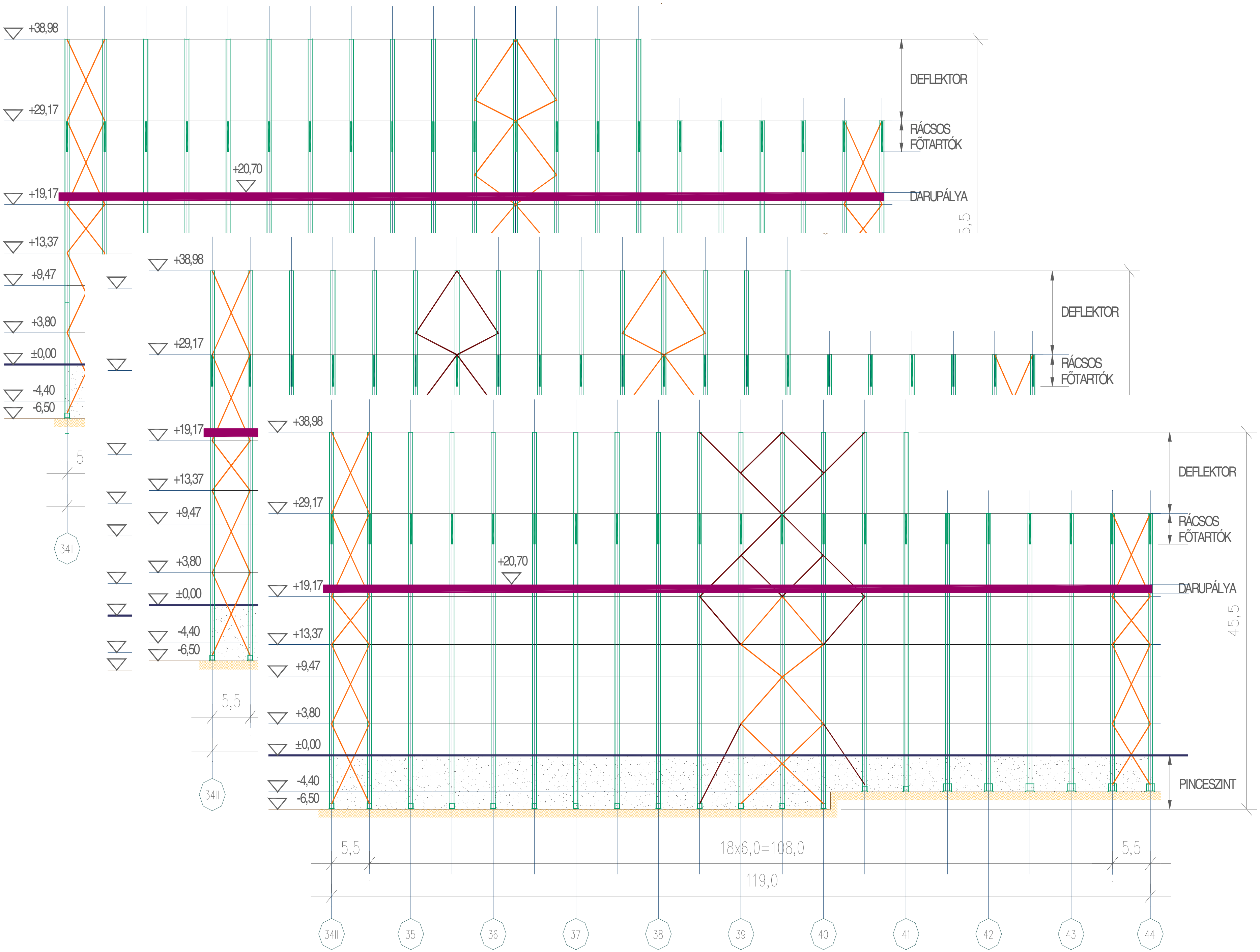


Structural fixes




+38,98
+29,17
+20,70
+19,17
+13,37
+9,47
+3,80
±0,00
-4,40
-6,50
DEFLEKTOR
RÁCSOS
FŐTARTÓK
DARUPÁLYA
PINCESZINT
45,5
5,5
18x6,0=108,0
119,0
34II
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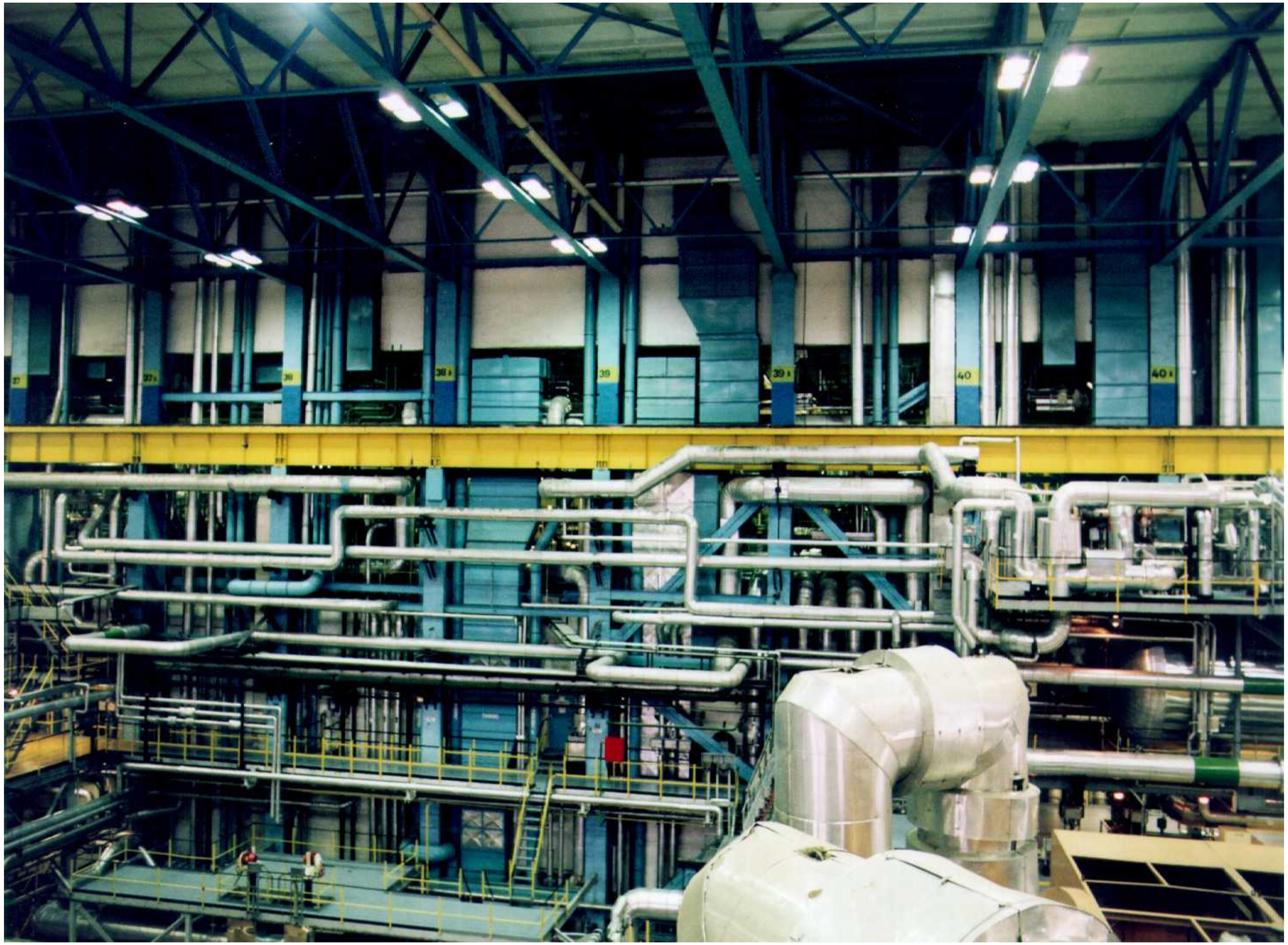
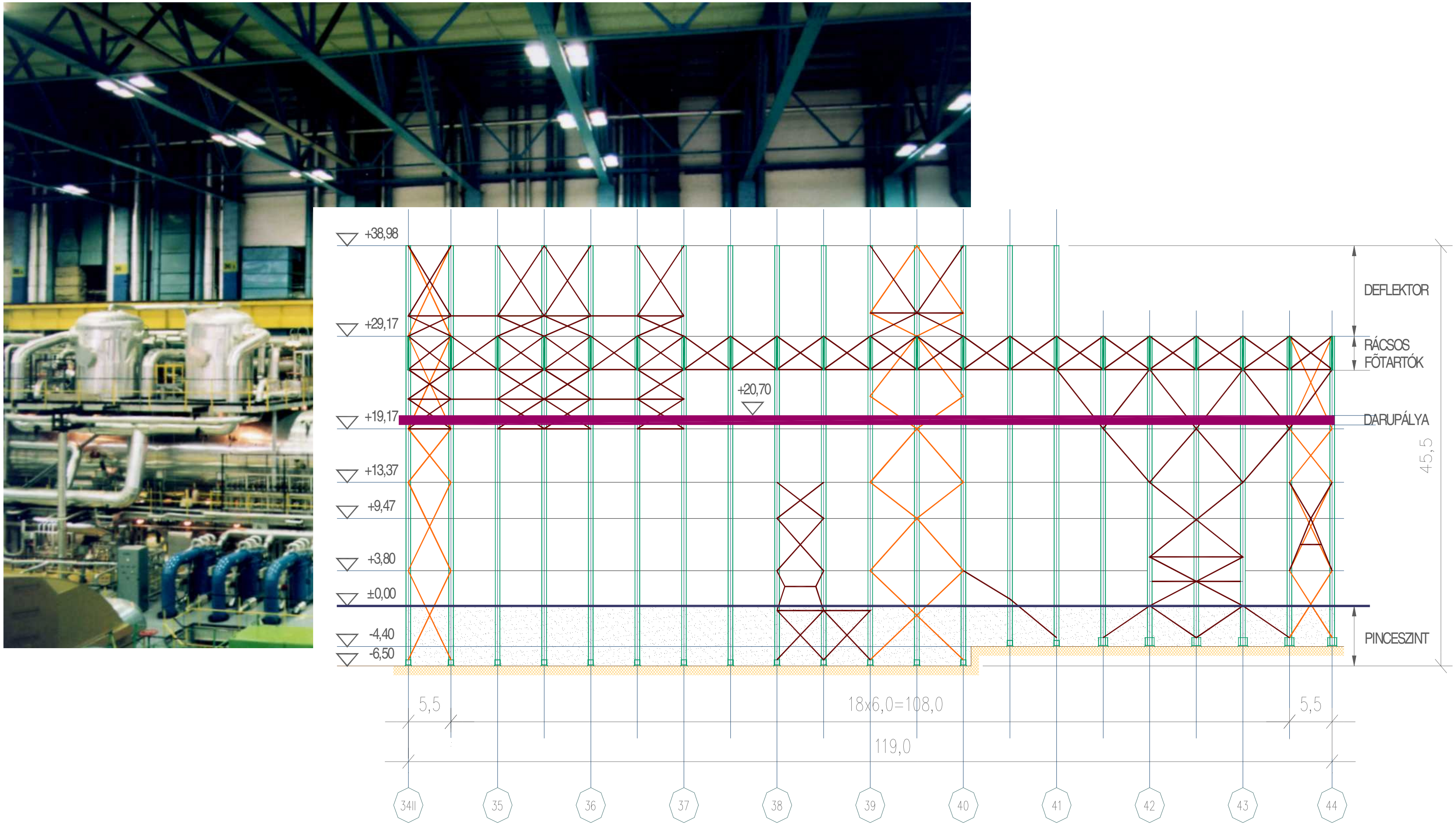


Longitudinal bracing structure

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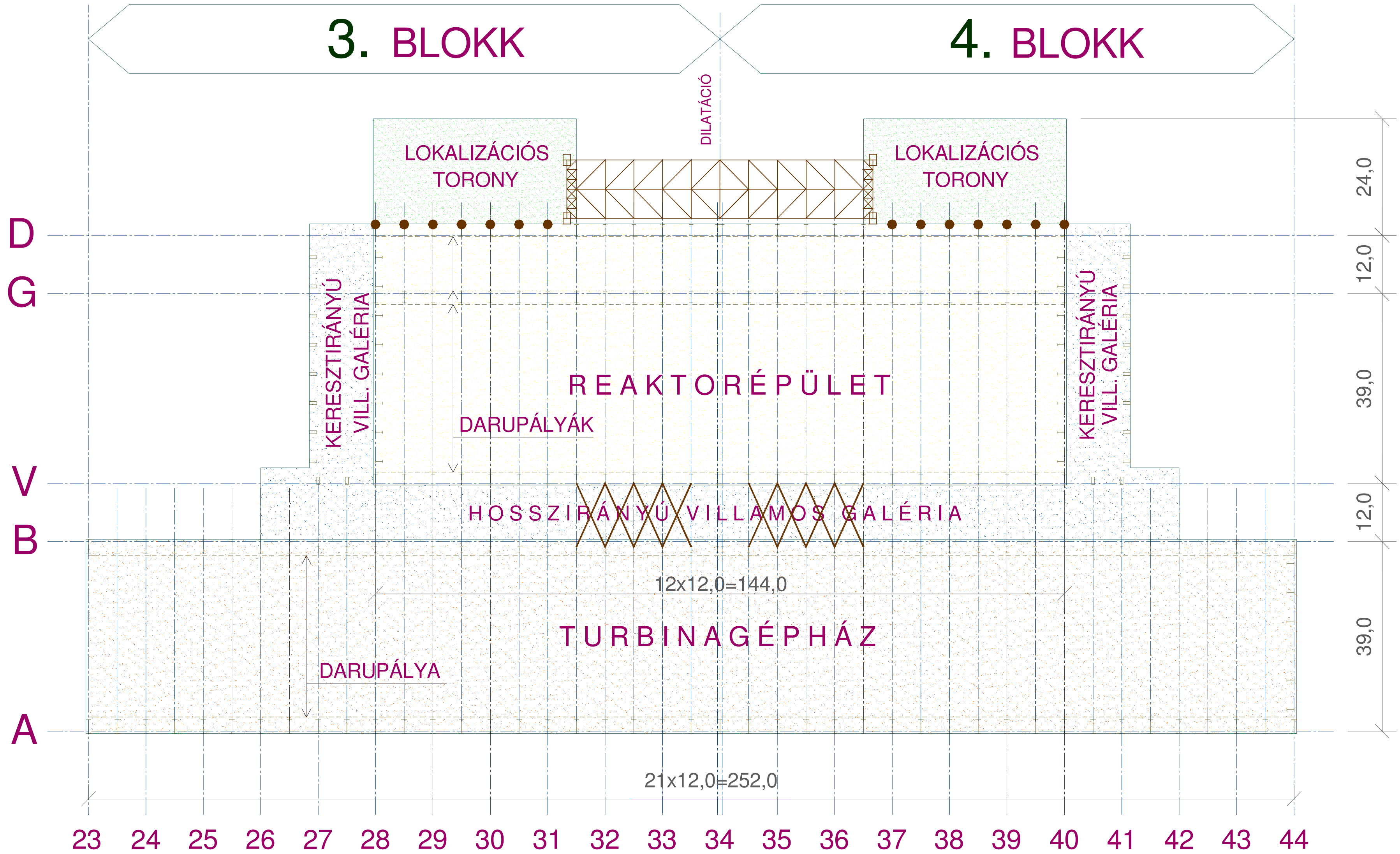
Bracing of the roof



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4. BLOKK
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D
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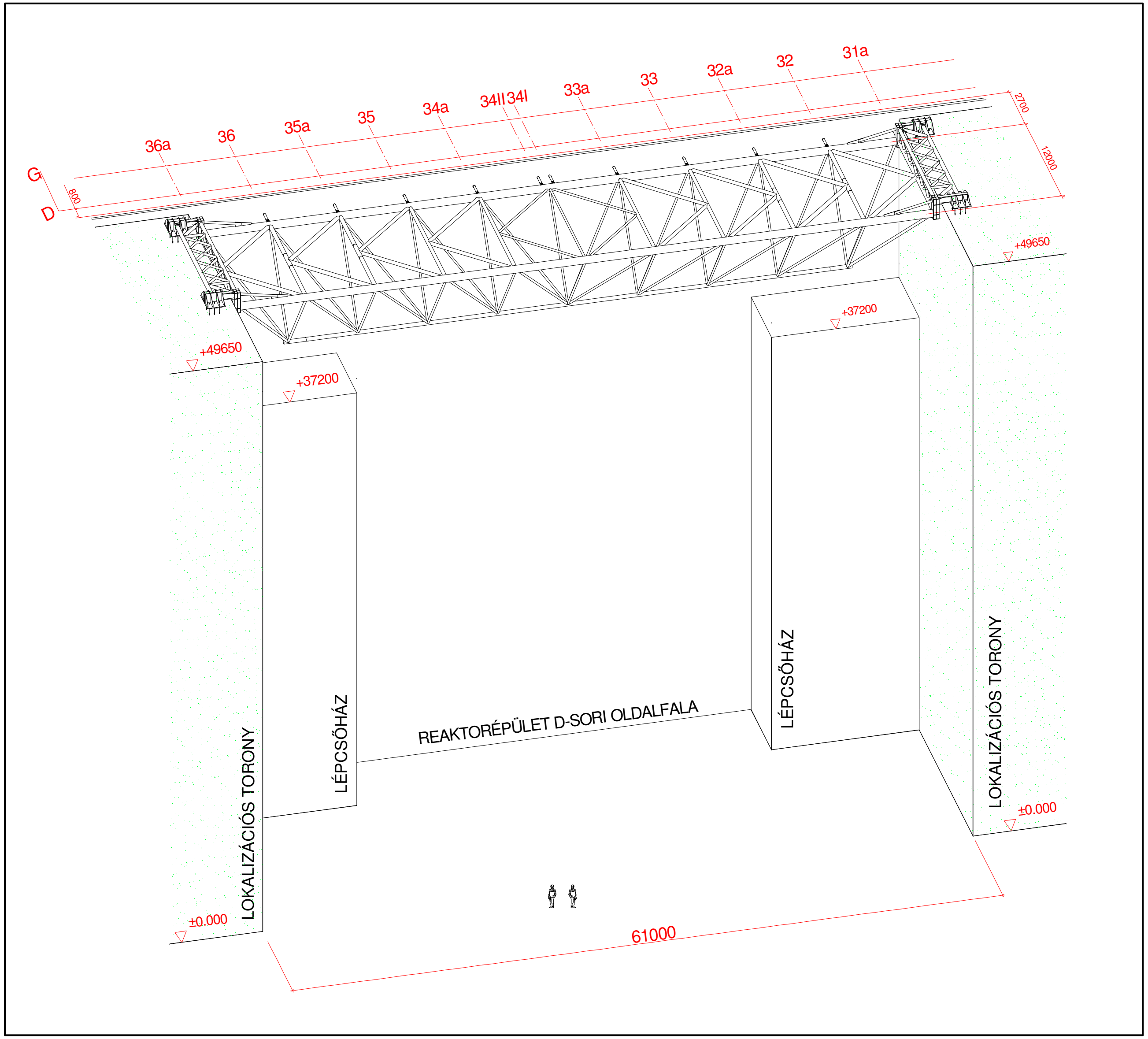
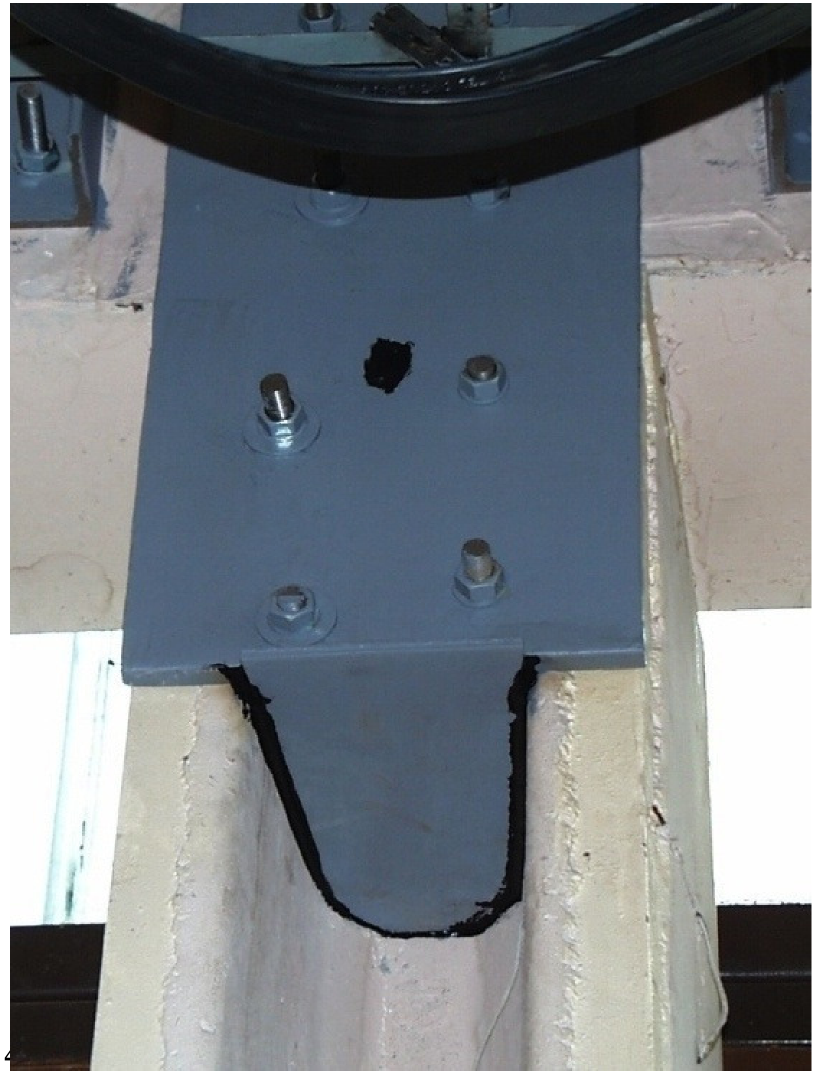
A
KERESZTIRÁNYÚ VILL. GALÉRIA
KERESZTIRÁNYÚ VILL. GALÉRIA
REAKTORÉPÜLET
DARUPÁLYÁK
HOSSZIRÁNYÚ VILLAMOS GALÉRIA
12x12,0=144,0
TURBINAGÉPHÁZ
DARUPÁLYA
21x12,0=252,0
24,0
12,0
39,0
12,0
39,0
23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44

„Paksi Atomerőmű üzemi főépületének földrengésállósági megerősítése”

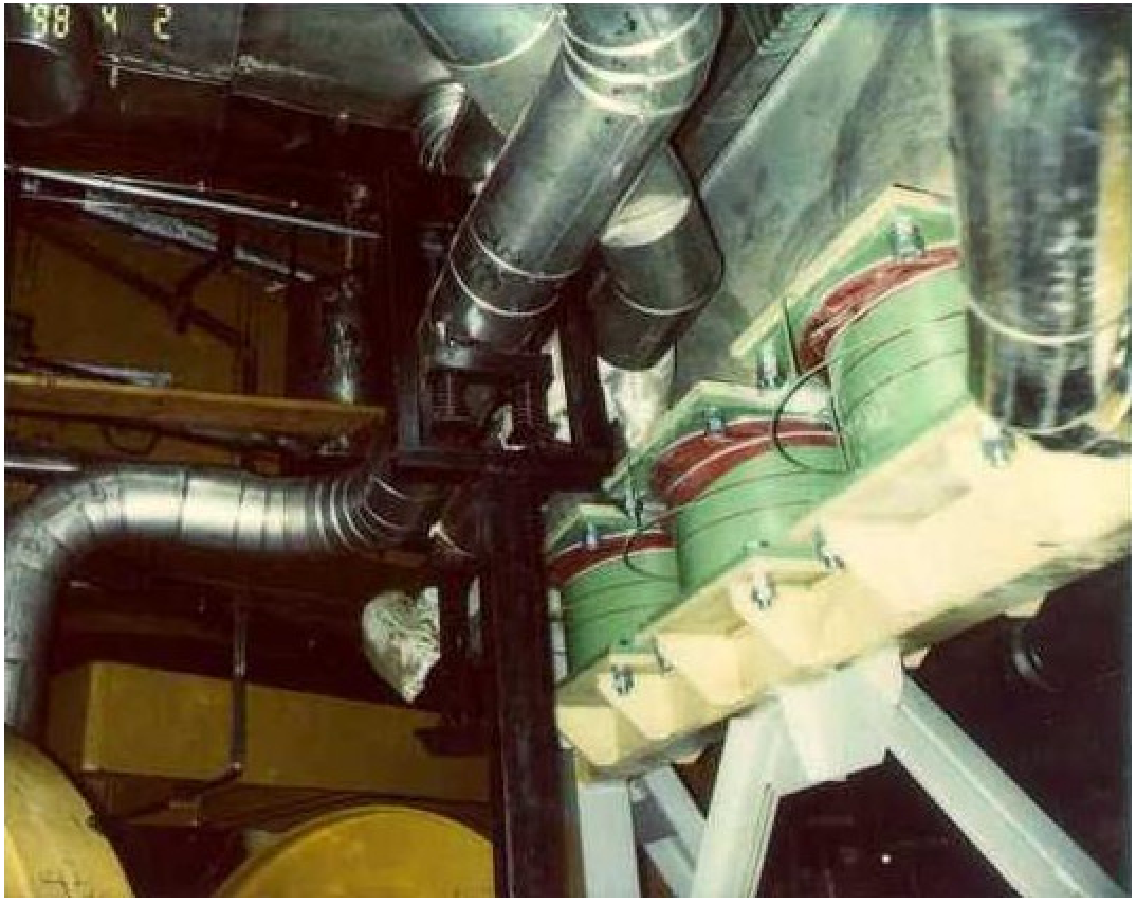


Fixing of nonductile joints



Easy-fix: fixing the cabinets and masonry

Viscous-dampers for piping and equipment



mvm paks nuclear

Overview of seismic safety upgrades

Easy-fix program

total number of items in the preliminary SSE list:	10184 for 4 units	improvements
total number of easy-fix items	5507	
mechanical equipment	202	anchorages
electrical equipment	465	anchorages
cable trays	2498	anchorages
I&C (cabinets, racks)	2061	anchorages and top bracing
brick walls	281	Steel frame fixes
total amount of steel for fixes	445 tons	
Safety related batteries replaced and properly fixed	yes	

Complex fixes

Qualification and upgrades	date	Volume of work
Electrical and I&C equipment	Easy fix, 1993-1995 -2002	450 t of steel structure added, batteries replaced, seismic instrumentation, Re-qualification of el. and I&C equipment
High energy pipelines of primary circuit and equipment	1997-1999	250 fixes (GERB viscous-dampers)
Building structure of the turbine and reactor hall	1999-2000	1360 t of steel structure added
Supporting frames of reactor building at the localization towers	2000-2001	300 t of steel structure added
Other classified pipelines of primary circuit and the equipment	1998-2000	760 fixes
Classified pipelines and equipment of secondary circuit, fixes of supporting steel structures in the turbine building	2000-2002	160 t of steel structure added
Classified pipelines of secondary circuit	2000-2002	1500 fixes
Other classified pipelines and equipment	2001-2002	80 fixes
Measures identified on the basis of seismic PSA	2002-	e.g. strengthening of all joints in the turbine building

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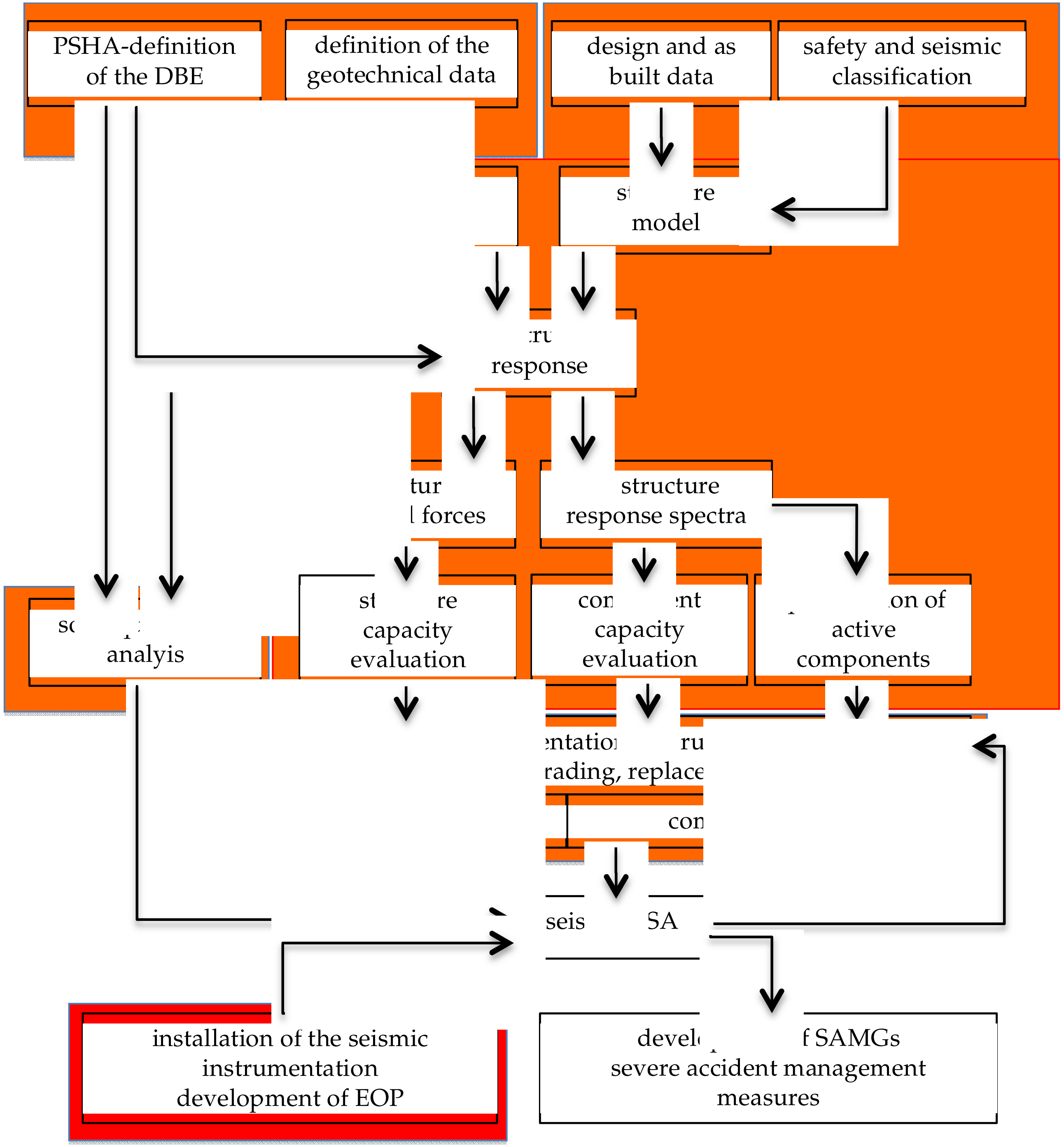


Post-EQ actions

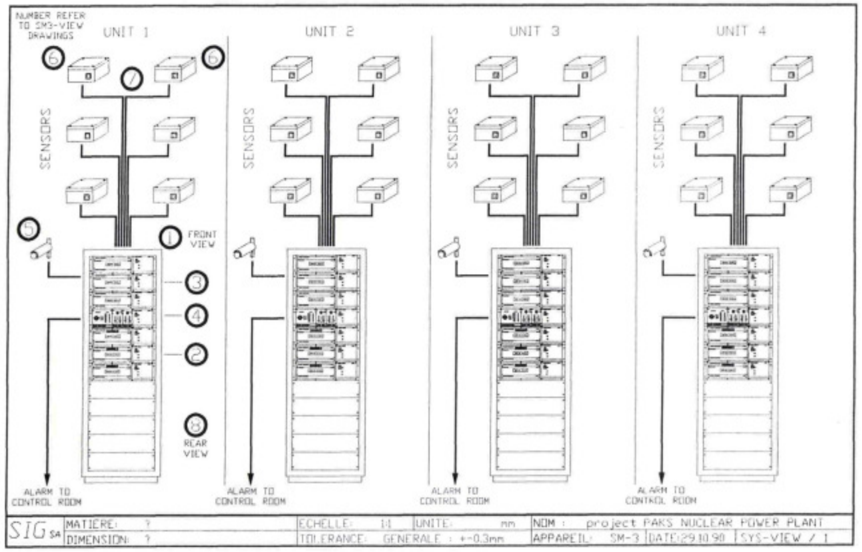
Assuming that the reactor remains in the operation during and after the earthquake, the operator shall shut down it **if the CAV≥0.16gs and amplitudes of the free-field response spectra in the frequency range of 1-10Hz larger than 0.2g**
The plant continues to operate if the above criteria are fulfilled.

The concept is developed on the basis of the following sources:

- Advisability of an Automatic Seismic Trip System (ASTS) in Nuclear Power Plants: RER/9/035, IAEA, Vienna, Austria, (1995), pp. 64-78.
- US NRC, Resolution of Generic Safety Issues: Item D-1: Advisability of a Seismic Scram (Rev. 1) (NUREG-0933, Main Report with Supplements 1–33)
- US NRC Regulatory Guide 1.166, "Pre-Earthquake Planning and Immediate Nuclear Power Plant Operator Post-Earthquake Actions."
- US NRC Regulatory Guide 1.167, „Restart of a Nuclear Power Plant Shut Down by a Seismic Event" U.S. NRC, March 1997
- IAEA Safety Reports Series No.66, Earthquake Preparedness and Response for Nuclear Power Plants, Vienna, 2011

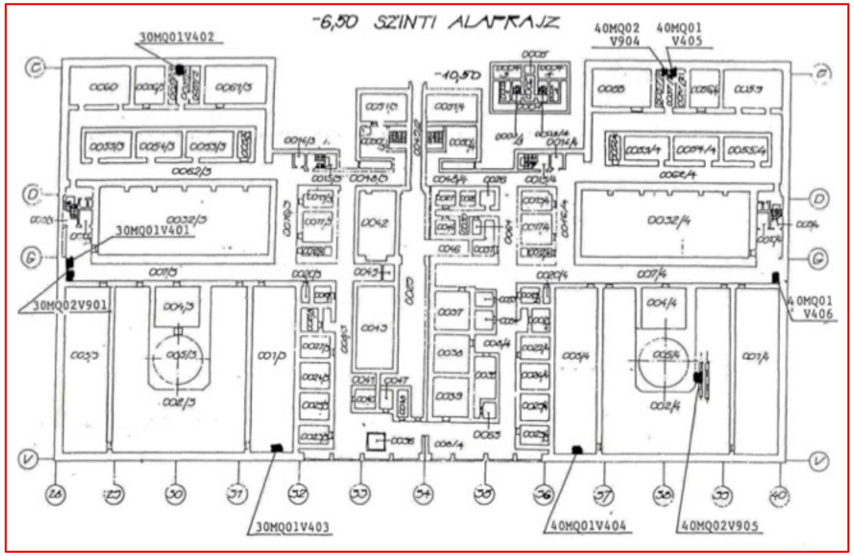
If the earthquake does not cause an equipment failure, which requires to shutdown reactor, according to the abnormal procedure the personnel should check the automatic closure of earthquake non-qualified equipment. If equipment failure occurs due to earthquake and it requires reactor shutdown the operator should use EOPs. More details regarding the procedures would be presented during site visit.

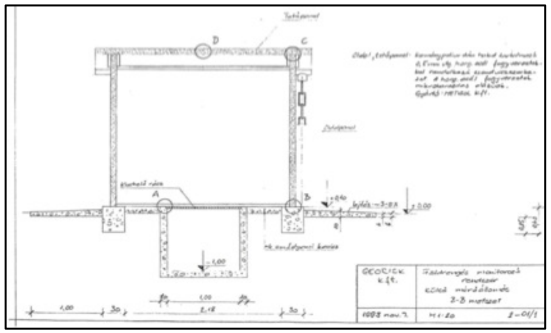
Seismic instrumentation



Number of detectors:
total 25, (13 recorder, 12 trigger)
1 free field
6 – 6 triggers on the basemat
12 recorders at critical poiont of the plant

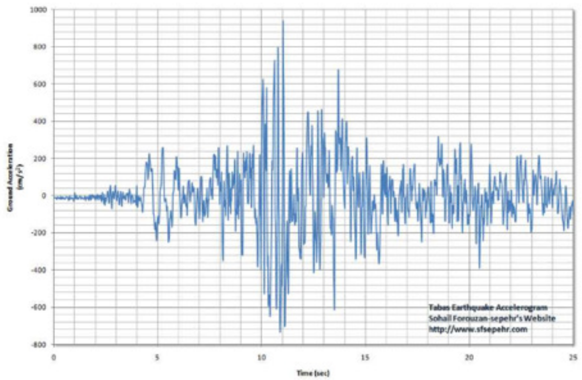
Type of detectors:
Triggers (switch):
type: AC-3, tri-axial accelerometer
manufacturer: SIG-SA
frequency range: 0.4 – 50 Hz
measuring scale: + - 0.5g
output voltage: + - 10V
current: 4.5 mA (max. 6 mA)
basic noise: 30 ng
Recorder:
type: AC-13, tri-axial accelerometer
frequency range: 0.2 – 50 Hz





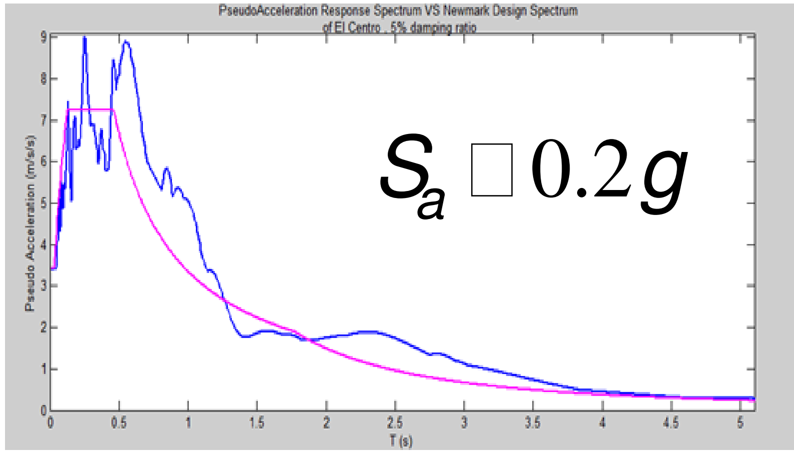
Procedure and criteria

Groud motion accelaration time history – measured at free-field



Calculate CAV and response spectra

$$CAV = \int_0^T |a(t)| dt \geq 0.16 gs$$



$$S_a \geq 0.2g$$

Decision on shut down

Current conditions at plant

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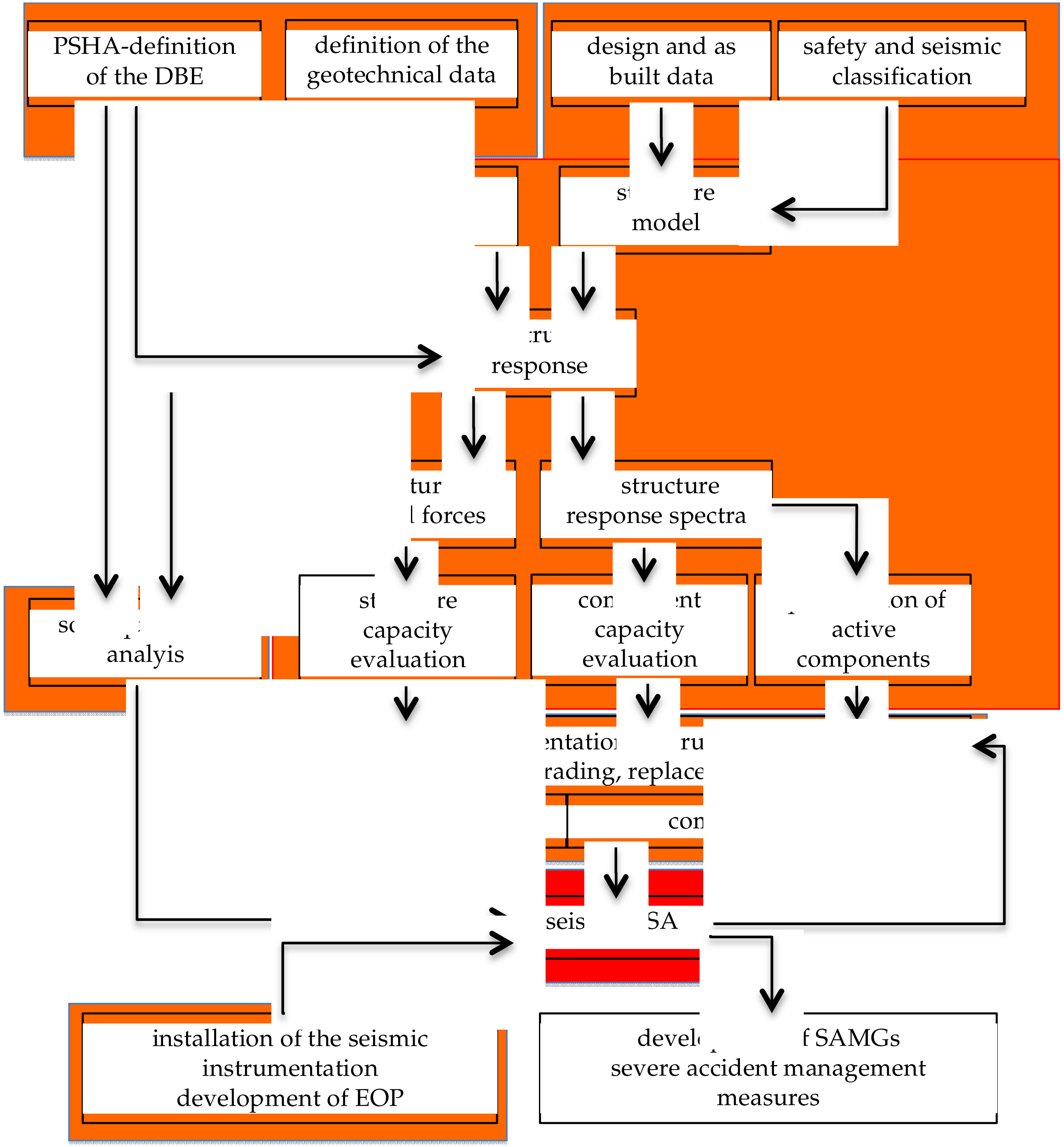


Assessment of the margins / CDF

For seismic event there are two widely acceptable methods for margin assessment:

✓Code Deterministic Failure Margin (with respect to an RLE)

✓Probabilistic Margin Assessment (PSA-type modeling)

✓Seismic PSA (seismic hazard curve, fragility curves, fault trees event trees)

Methodology described in the following:

- **EPRI (Electric Power Research Institute) 1991. A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1). EPRI NP-6041-SL, Rev. 1. Palo Alto, California: Electric Power Research Institute.**
- **Budnitz, R. J., et al., An Approach to the Quantification of Seismic Margins in Nuclear Power Plants, NUREG/CR-4334, U. S. Nuclear Regulatory Commission, August 1985**

External-events PRA methodology, American National Standard, ANSI/ANS-58.21-2007

ASME/ANS RA-S–2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications

NUREG/CR-2300, “PRA Procedures Guide: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants”

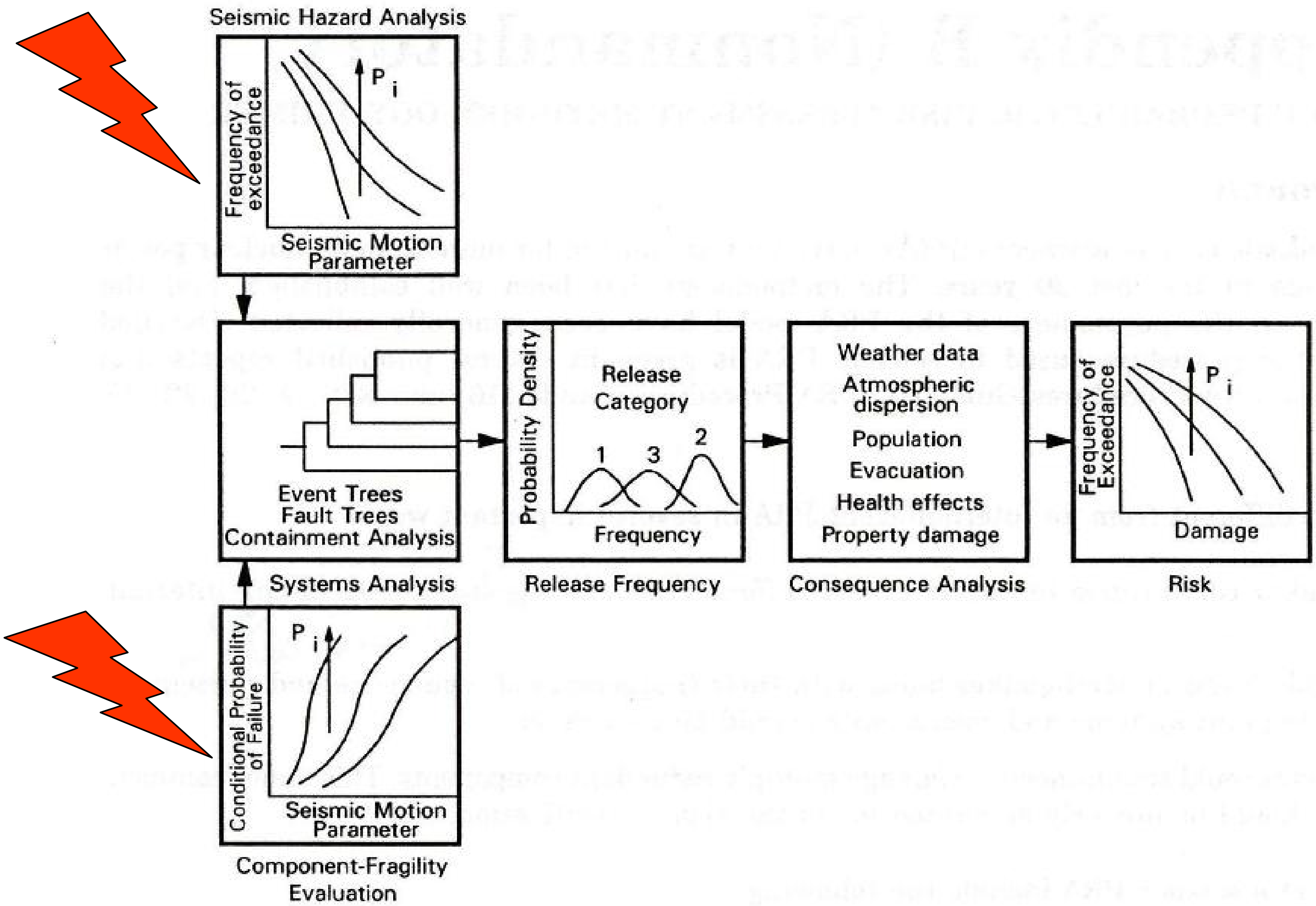
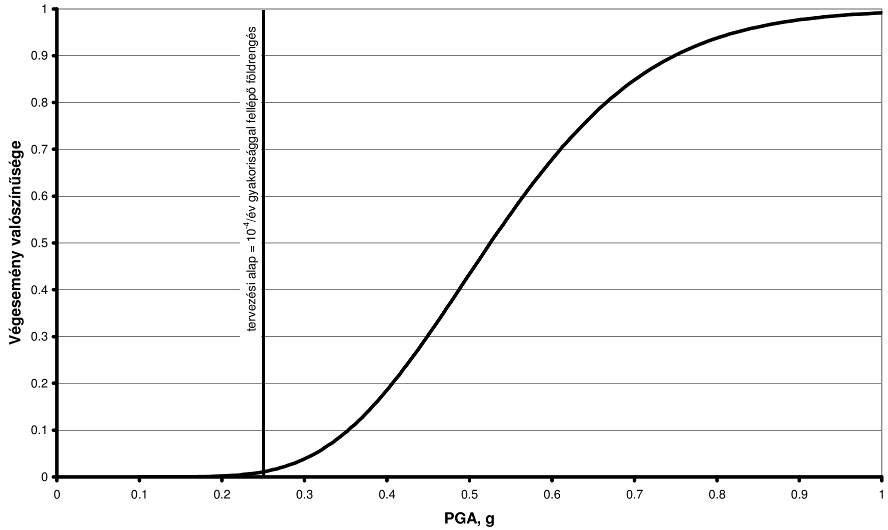


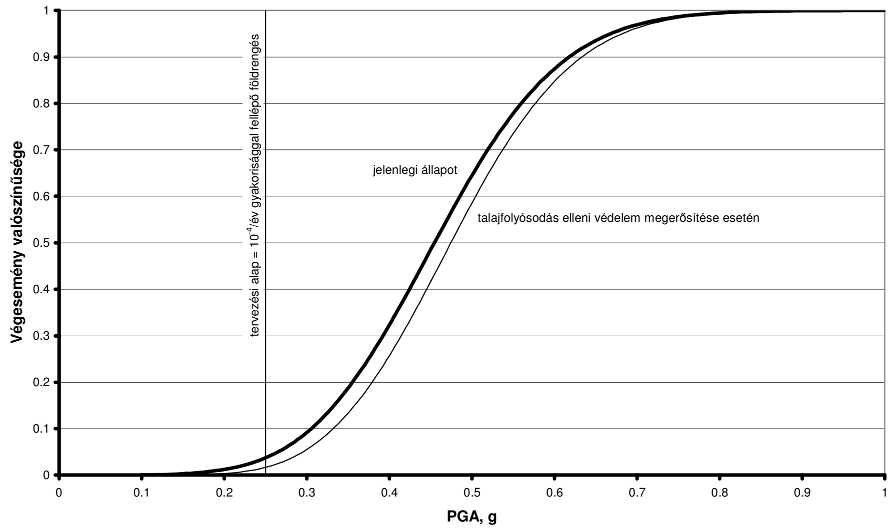
Figure B.1.—Schematic overview of a seismic PRA (P_i indicates the subjective probability weight assigned to each curve $_i$)

Fragilities and HCLPFs

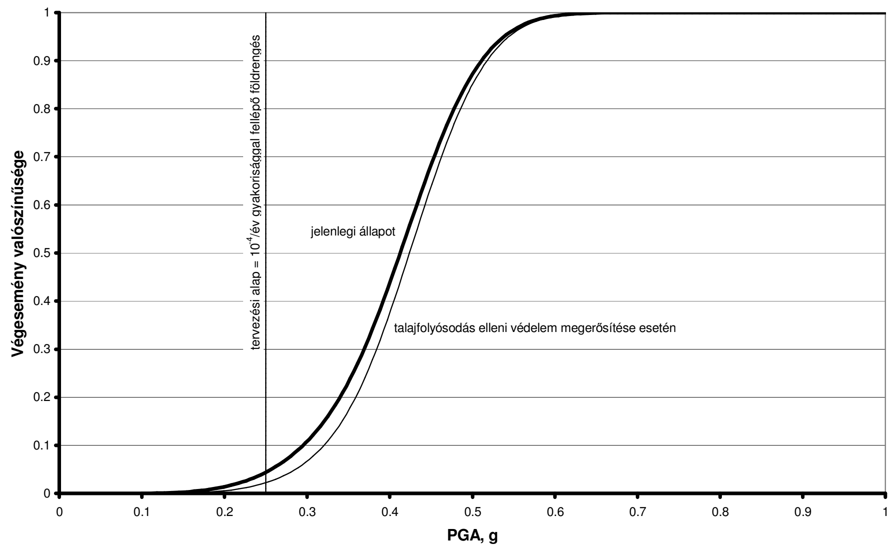
CDF seismic 10-5/a order of magnitude



Loss of containment



Loss of emergency power supply



Loss of ultimate heat-sink

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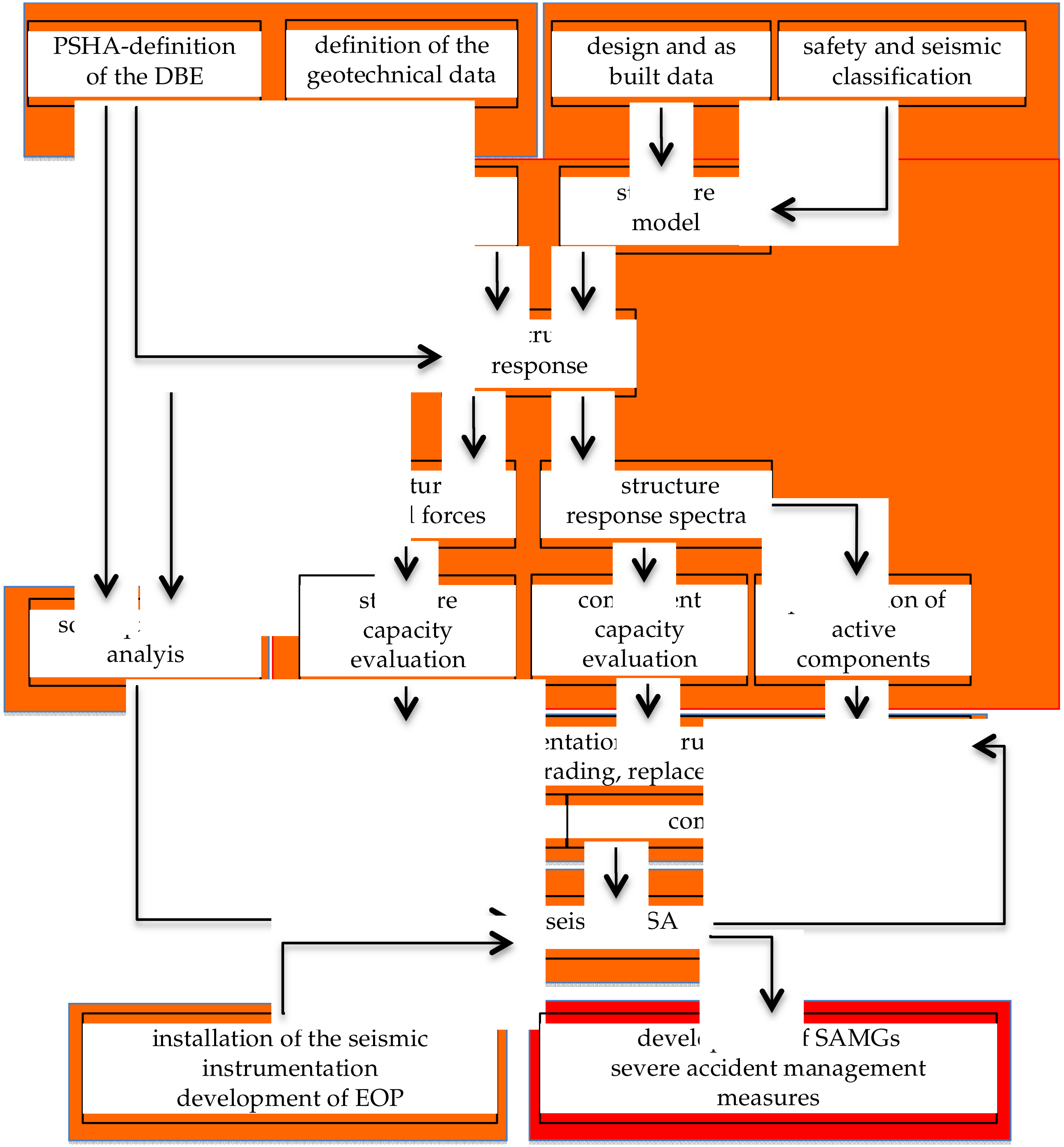

Stress-test: Earthquake – measures envisaged

- Qualification of some structures
- Analysis of need for automatic reactor shutdown
- Improvement of fixing of maintenance materials and objects stored at the units
- Further investigation of liquefaction and building settlement
- Modification of ESWS filters and main condenser lines
- Modification of EOPs to support response to seismic events
- Revision of communication abilities after an earthquake
- Revision of seismic classification database

Consequences of the liquefaction

The failure mode is the settlement.

The lost of the stability by toppling can be excluded. of the liquefiable layer, the drainage of that layer, the relatively deep embedding of the building, low center of gravity)

There is no re

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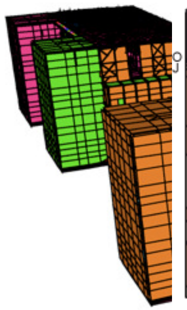
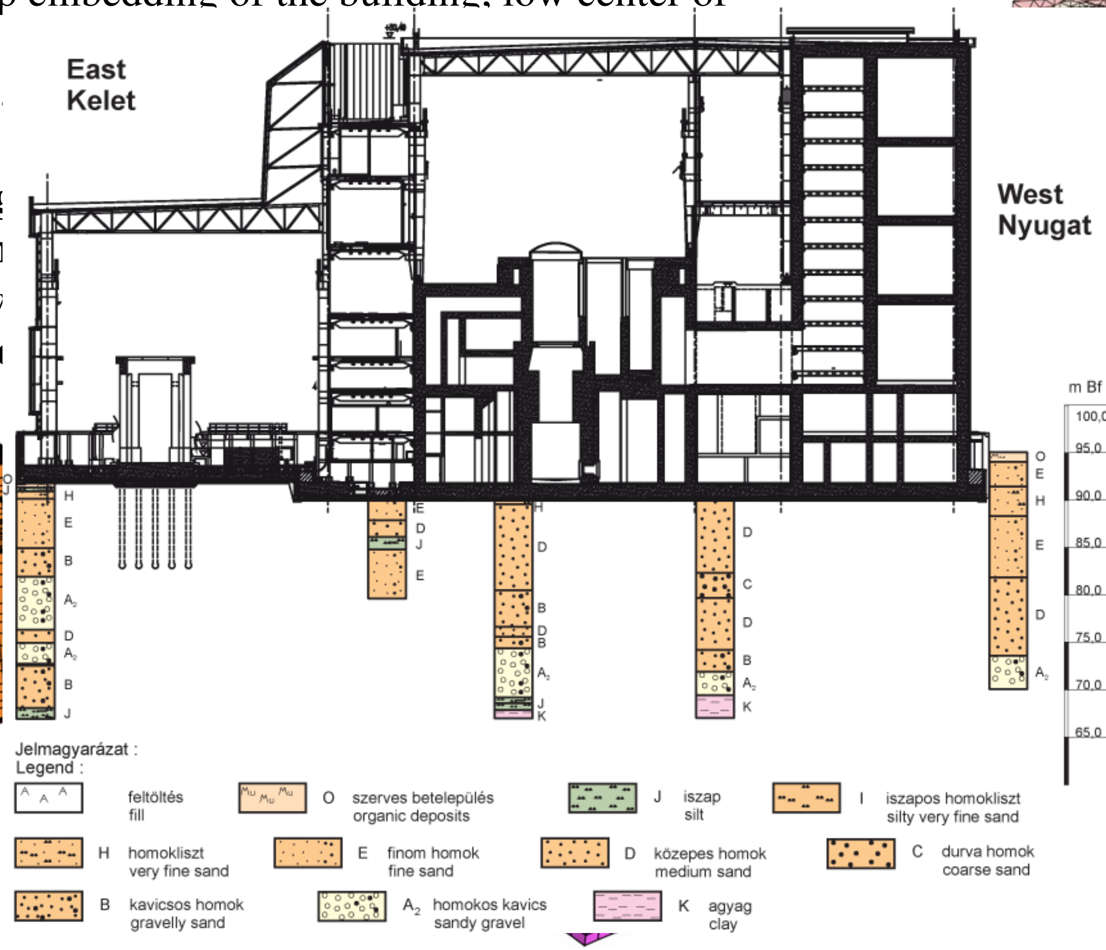
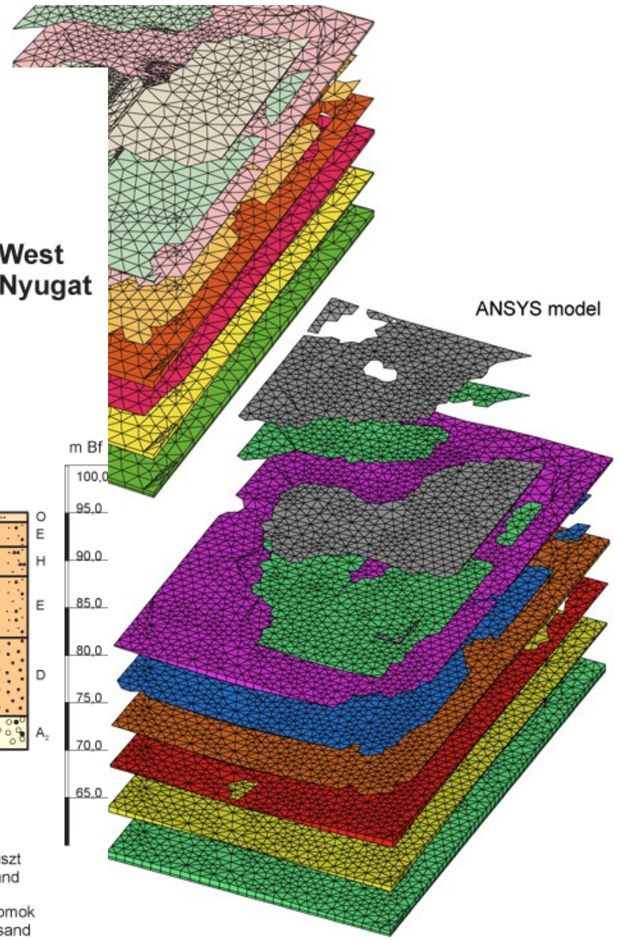
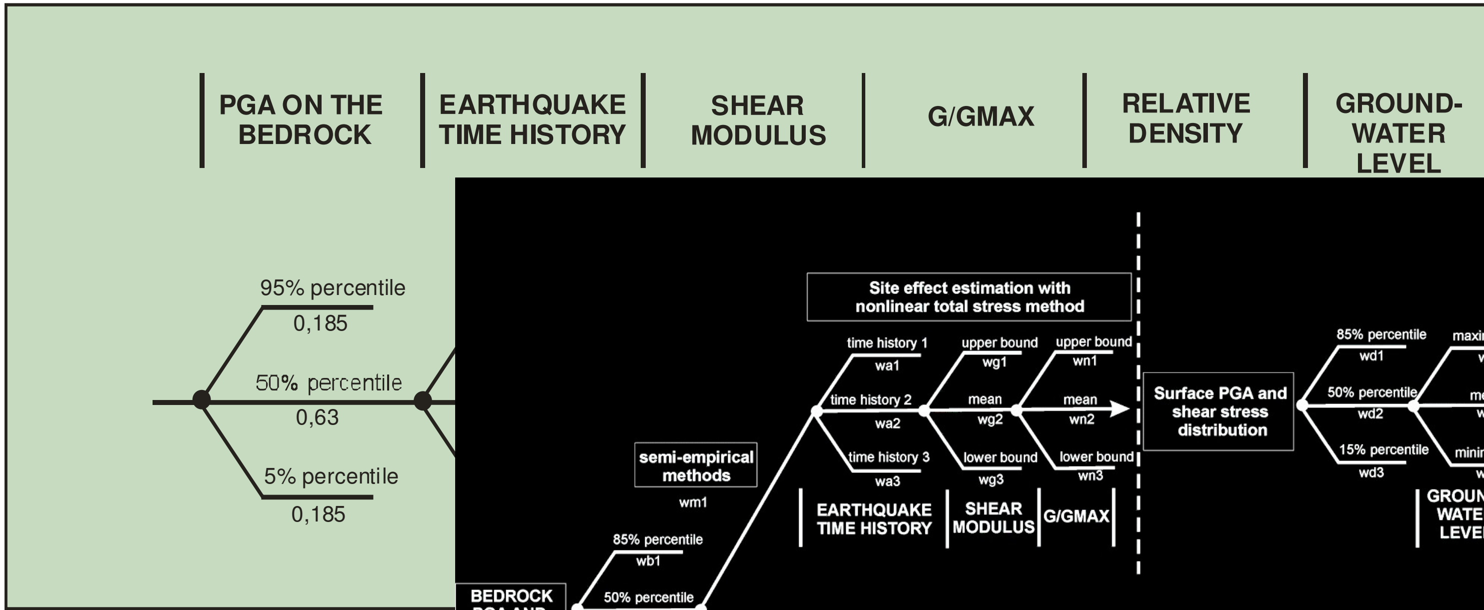
COMPREHENSIVE BUILDING MOVEMENT ANALYSIS

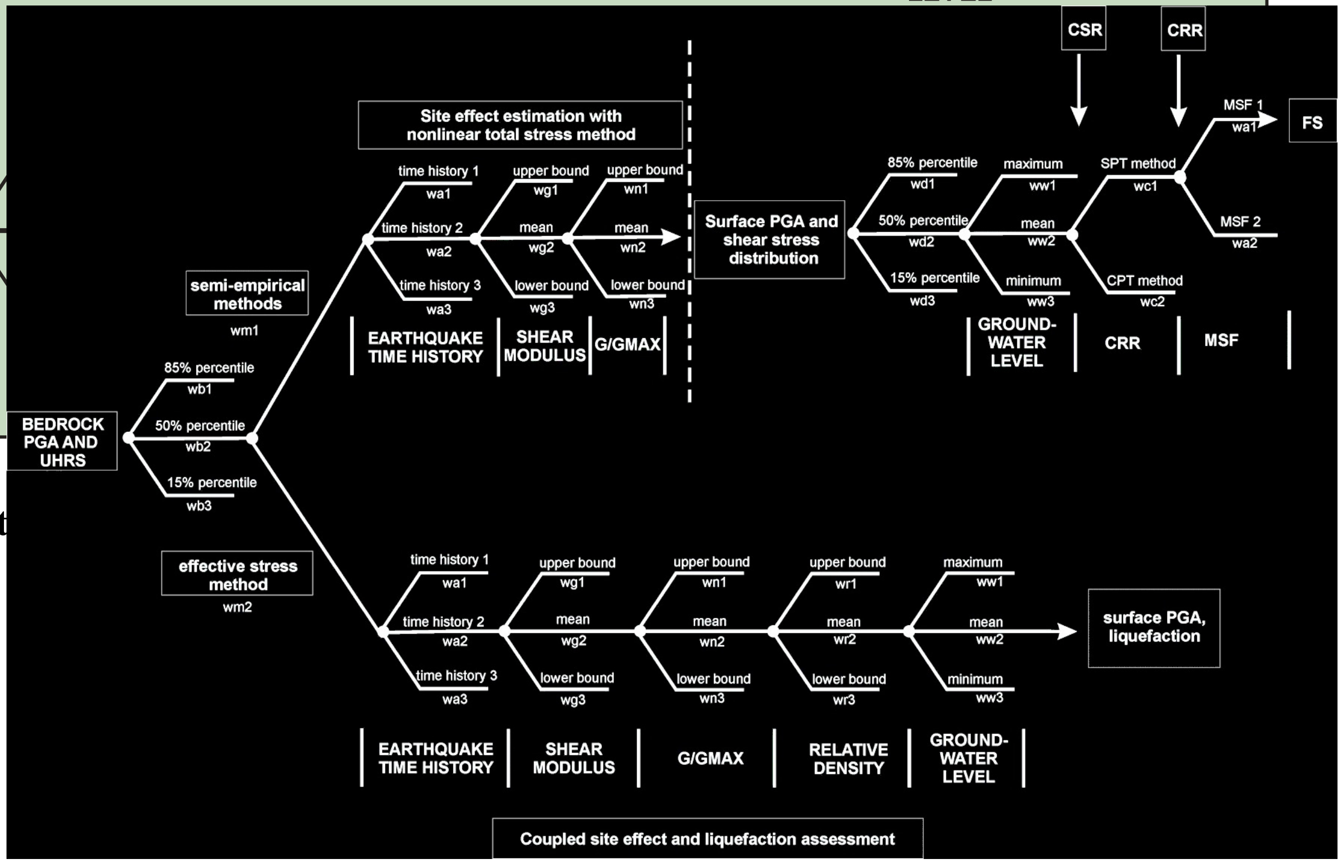






Logic tree for liquefaction analysis





Győri E. et al (2011), Eart
Geoph. Hung., Vol. 46(3),

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