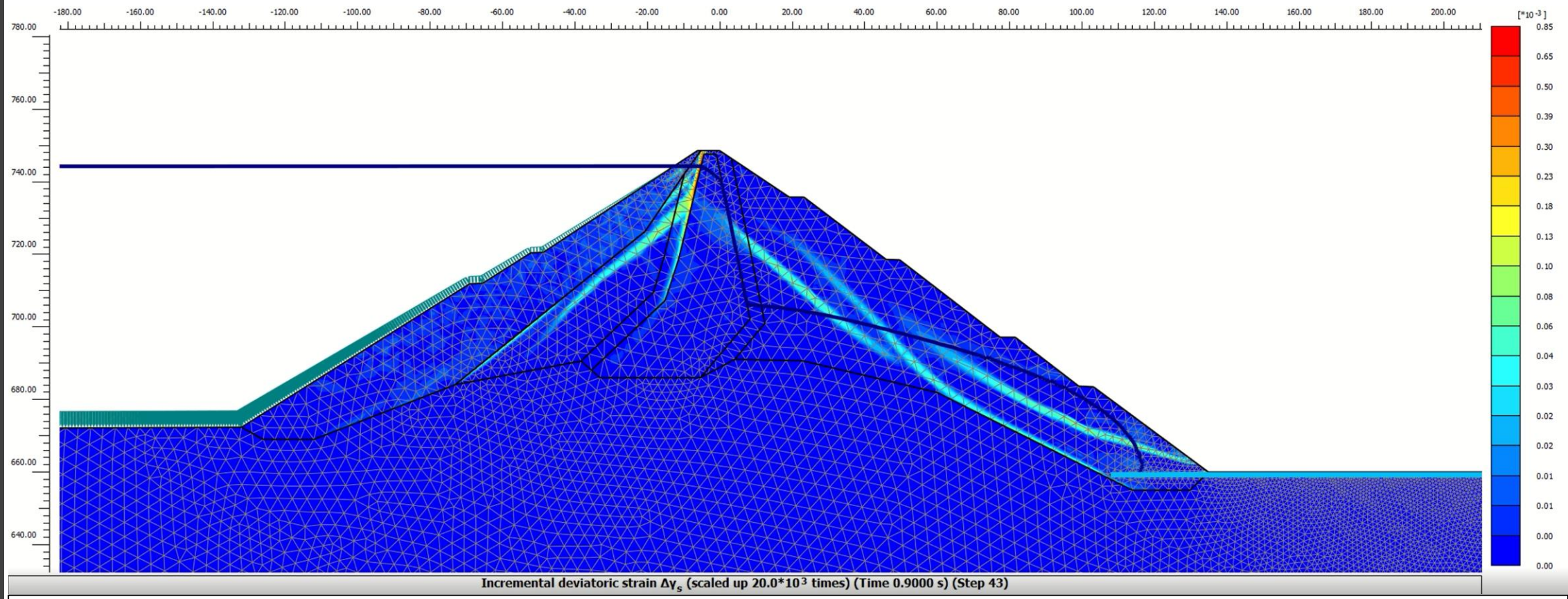
BAUSCHADENANALYSE PS-KW

SCHADENSAUSMASS UND URSACHEN
ERMITTLUNG DER WERTMINDERUNG
PROJEKTUMFELD UND BAUVERTRAGLICHER HINTERGRUND

ERDBEBENVERHALTEN VON DÄMMEN



VORGABEN GEMÄSS ERDBEBENRICHTLINIE FÜR STAUDÄMME
METHODEN UND EINSCHRÄNKUNGEN
EINFLUSS DER AUFSTANDSTOPOGRAPHIE

THEMEN

A) BAUSCHADENANALYSE NEU ERRICHTETES PUMPSPEICHERPROJEKT

Situation

- Unfälle im Zuge der Ausbruch- bzw. Schutterungsarbeiten
- Massive Betonschäden und Undichtigkeiten im gesamten Hochdruckabschnitt
- Umfangreiche Betonschäden und Undichtigkeiten im gesamten Niederdruckabschnitt
- Massive Betonschäden und Undichtigkeiten im Schachtwasserschloss

Aufgabe im Zuge eines Streitschlichtungsverfahrens

- Schadensausmaß
- Ursachenanalyse
- Wertminderung und Zuordnung zu den Parteien
- Hintergrundanalyse für Folgeprojekt in Eigenregie
  - Gesamtprojektkonfiguration
  - Bauvertragsmodel
  - Bieterwahl

THEMEN

B) ERDBEBENVERHALTEN VON SCHÜTTDÄMMEN

- Stand der Richtlinien und verfügbare Methoden
- Bewertung von bestehenden Unterlagen zu geotechnischen Untersuchungen zur Ableitung von Stoffmodellen
- Einfluss der Aufstandstopographie auf das Erdbebenverhalten
- Vergleich der Sensitivität von Methoden

BAUSCHADENANALYSE PSPP
ÜBERBLICK

NON EXISTING PROJECT, INSPIRED BY A REAL CASE STUDY

- 400 MW PSPP without natural inflow
- Upper and lower reservoir, each with a capacity of 3.2Mio m^3;
- 700m vertical HP shaft; 380m sub horizontal HP tunnel, 1330m LP tunnel, all with final concrete lining
- Steel lined bifurcation;
- 2 power-house caverns a) machine cavern + MIV b) 2 main transformers and frequency converter
- 70m height surge shaft with concrete lining;
- outdoor switch-yard connects the PSPP to the Grid

BAUSCHADENANALYSE PSPP
DEFECTS

DETAILS






BAUSCHADENANALYSE PSPP
DEFECTS

DETAILS






BAUSCHADENANALYSE PSPP
DEFECTS

DETAILS






BAUSCHADENANALYSE PSPP
EXTENT OF DEFECTS

EXTEND OF DEFECTS – HP SECTION

. LEACKAGES AND STRUCTURAL DEFECTS ALONG THE COMPLETE HP SHAFT – 700m

. LEACKAGES AND STRUCTURAL DEFECTS ALONG THE COMPLETE HP TUNNEL – 380m

. CONSOLIDATION AND STRUCTURAL GROUTING NOT SUCCESSFULL

. GROUTING VOLUMES VERY LOW PRESSURES UP TO 12 BAR, NO TPA MONITORING

. THE COMPLETE HP PART WAS EQUIPPED WITH A SECONDARY PVC MAMBANE LINING

CLAMPING STRIPS + BOLTS

. EXTERNAL WATER PRESSURE DURING DEWATERING
. TEMP. DEPENDENT VARIATIONS
. POT. DETACHMENT OF STRIPS AND MEMBRANE

EXTENT OF DEFECTS

EXTEND OF DEFECTS – SURGE SHAFT

. LEACKAGES AND STRUCTURAL DEFECTS ALONG THE COMPLETE SURGE SHAFT – 70m

. CONCRETE REPAIR PATCHWISE NOT FEASIBLE DUE TO EXTEND OF DEFECTS

. THE COMPLETE SURGE SHAFT WAS EQUIPPED WITH A SECONDARY CONCRETE LINING

. REMOVAL OF DEFECT CONCRETE AND EXPOSURE OF REINFORCEMENT
. BONDING PRIMER ON REMAINING CONCRETE AND REBARSS
. IMPLEMENTATION OF NEW CONCRETE LINING

. POT. BONDING ISSUES
. REDUCTION OF SURGE CAPACITY

BAUSCHADENANALYSE PSPP
EXTENT OF DEFECTS

EXTEND OF DEFECTS – LP SECTION

. LEACKAGES AND STRUCTURAL DEFECTS ALONG THE COMPLETE LP TUNNEL – 1300m

. 257 REPAIR PATCHES

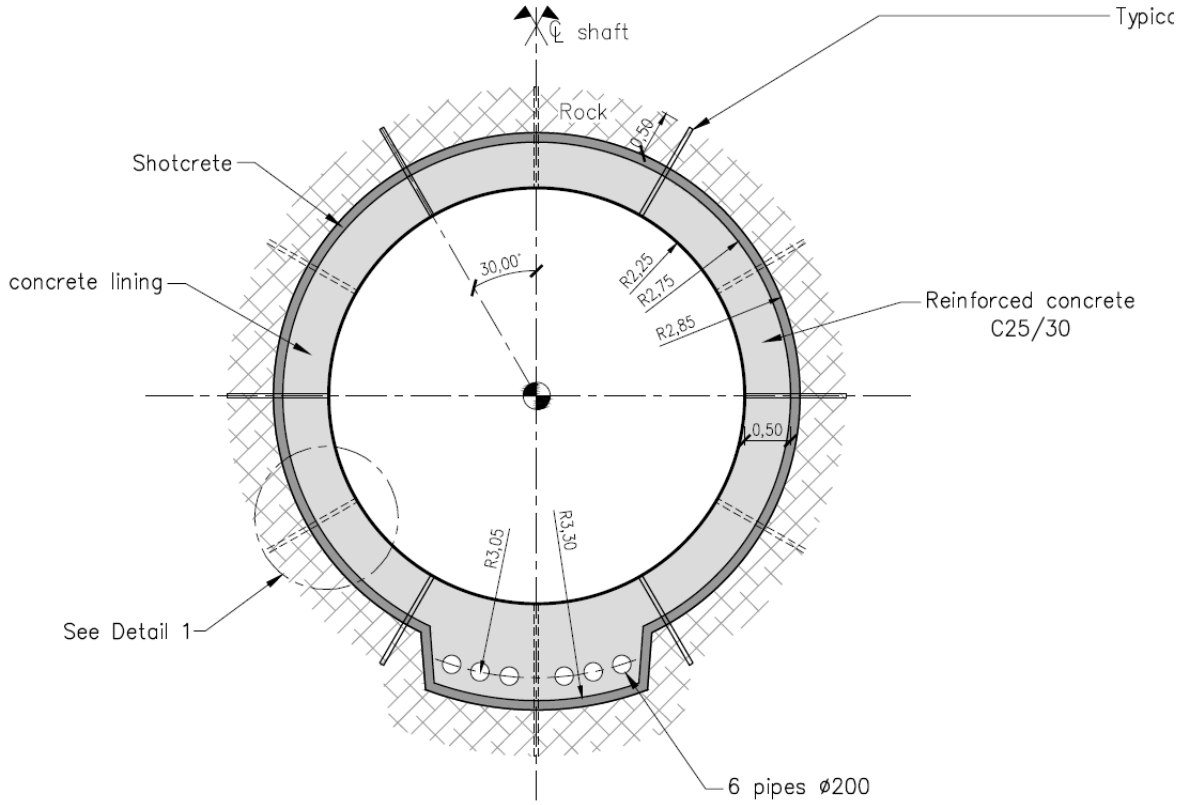
. QUALITY CRITERIA NOT MET TO A GREAT EXTEND

. REMOVAL OF DEFECT CONCRETE AND EXPOSURE OF REINFORCEMENT
. BONDING PRIMER ON REMAINING CONCRETE AND REBARSS
. IMPLEMENTATION OF HIGH PERFORMANCE MORTAR

. POT. BONDING ISSUES
. EVENESS AND SURFACE QUALITY CRITERIA NOT MET
. HIDDEN DEFECTS NOT IDENTIFIED

BAUSCHADENANALYSE PSPP
DESIGN

HP SHAFT



General Layout

. 500m of vertical extension

. Inner diameter of 4.5m, wall thickness 0.5m

. Excavation with raise-boring

(primary drilling to down, widening bottom up)

. Primary support with shotcrete

. Final lining with reinforced concrete

. Structural/consolidation grouting one sequence

. Concrete implementation with slip-formwork

. Concrete supply with mixing trucks from extern plant

. Concrete strength

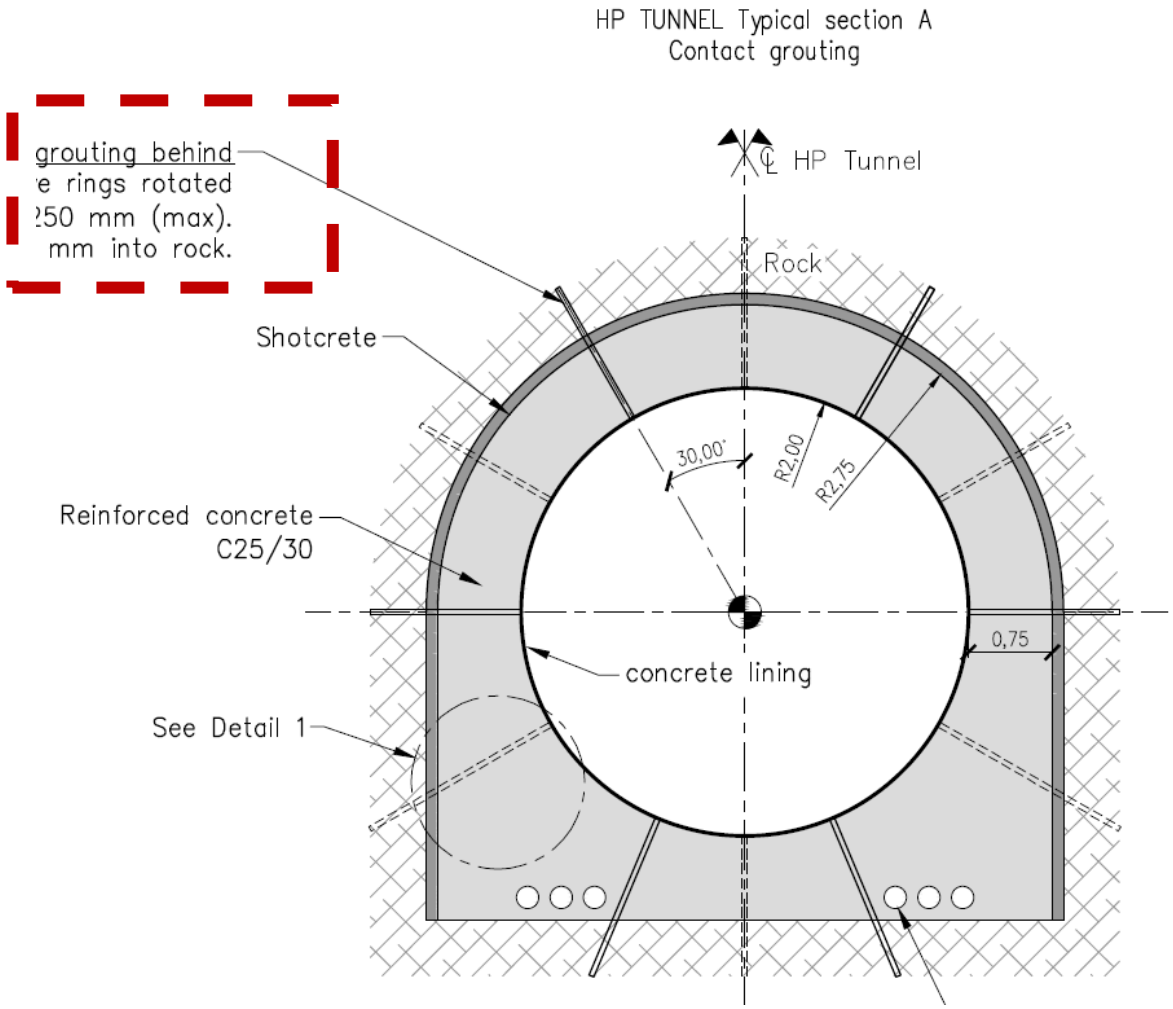
. 30MPa as per design drawings

. 50Mpa as per updated specifications

BAUSCHADENANALYSE PSPP
ASSESSMENT OF THE DESIGN

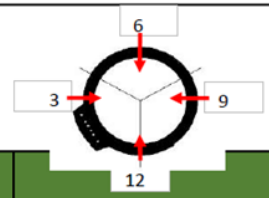
. FE modelling does neither consider excavation sequences / rock mass response nor primary stress states or temporary support

. Grouting specifications not sufficient
  . rock mass / joint characteristics
  . required grout mix design
  . required grout pressure and volume



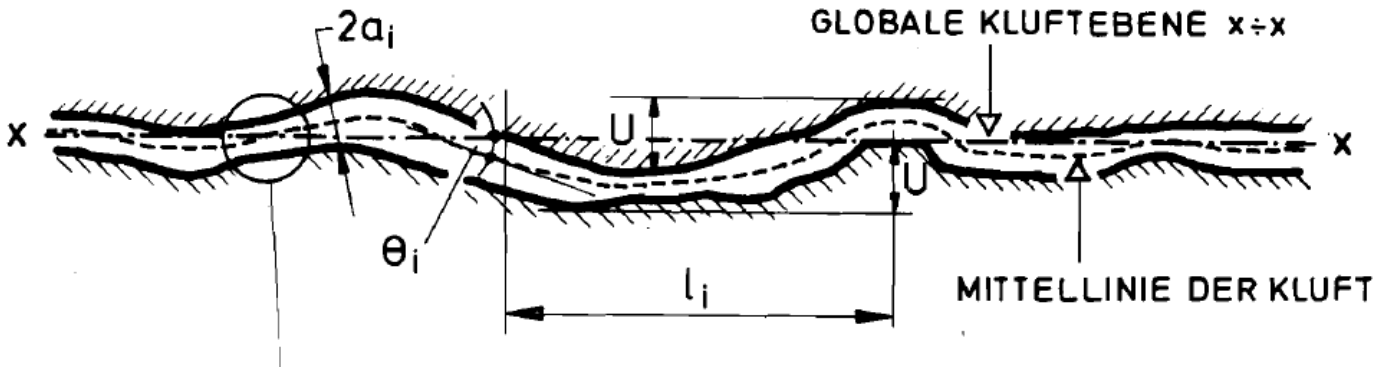
BAUSCHADENANALYSE PSPP
DESIGN

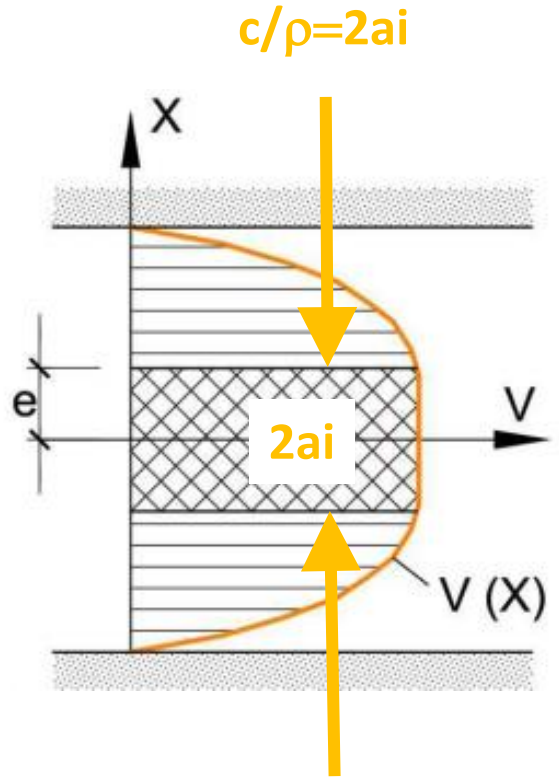
							Total length grouted:	61			
							1.2m hole volume (L):	2.36			
							convertion 1Kg cement to liter grout:	0.93			
							Grout Volume (L):	150			
							Average liter grout / m of Shaft:	0.32			
Activity:	CONTACT GROUTING VALIDATION						Pump Flow rate (L/SEC)	0.167			
Location:	HP SHAFT						Pipe Volume (L)	5.4			



Row No.	Elevation	Direction	Driling [m] Length	Theoretical Volume (L)	Grout Date	W/C ratio	Grouting Duration (seconds)	Grout Vol (L)	Pressure (bar)	Pressure after 5min (bar)	COMMENTS
1	-85	11	1.00	1.96	6/12/17	0.6	12	2.00	8	5	
2	-82	6	1.00	1.96	6/12/17	0.6	13	2.17	9	8	
2a	-82	10.5	1.05	2.06	6/12/17	0.6	13	2.17	8	7	
3	-80	11	1.00	1.96	6/12/17	0.6	12	2.00	8	6	
4	-78	6	1.00	1.96	6/12/17	0.6	13	2.17	7	5	
4a	-78	12	1.00	1.96	6/12/17	0.6		0.00			not possible to install packer - hole too large for mechanical, water ingress not allow to block with fast cement - hole not tested
5	-76	10	1.00	1.96	6/12/17	0.6	12	2.00	7	6	
6	-74	7.5	1.00	1.96	6/12/17	0.6	13	2.17	8	7	
7	-72	11	1.00	1.96	6/12/17	0.6	12	2.00	8	5	
8	-69	6	1.10	2.16	6/12/17	0.6	14	2.33	8	6	
8a	-69	11	1.00	1.96	6/12/17	0.6	12	2.00	7	5	
9	-66.5	9	1.05	2.06	6/12/17	0.6	11	1.83	8	5	
10	-62	7	1.40	2.75	5/12/17	0.6	17	2.83	8	6	
11	-58	10.5	1.10	2.16	5/12/17	0.6	14	2.33	8	8	
12	-56	6	1.00	1.96	5/12/17	0.6	15	2.50	8	8	
12a	-54	6	1.00	1.96	5/12/17	0.6	12	2.00	8	5	
13	-54	10	1.00	1.96	5/12/17	0.6	12	7.00	7	5	
14	-52	6	3.00	5.89	5/12/17	0.6	37	6.17	8	6	
14a	-52	11.5	2.40	4.71	5/12/17	0.6	29	4.83	8	0	Water ingress from air vent once start to grout, pressure rise to 8 bar in 13 sec, fall down to 0. Try several times with same result - every aditionall take is 1-2 seconds to build pressure.
15a	-49	6	2.40	4.71	5/12/17	0.6		0.00			grout leak detected from crack intersects the hole - test stopped
15	-49	11	2.40	4.71	5/12/17	0.6	32	5.33	8	0	Water ingress from air vent once start to grout, pressure rise to 8 bar in 13 sec, fall down to 0. Try several times with same result - every aditionall take is 1-2 seconds to build pressure.
16	-46	6	2.40	4.71	5/12/17	0.6		0.00			water leak detected from small crack 10 cm under the hole - test stopped
16a	-46	11	2.30	4.52	5/12/17	0.6	30	5.00	8	0	Water ingress from air vent once start to grout, pressure rise to 8 bar in 13 sec, fall down to 0. Try several times with same result - every aditionall take is 1-2 seconds to build pressure.

OPENING WIDTH AND GROUT MIX DESIGN

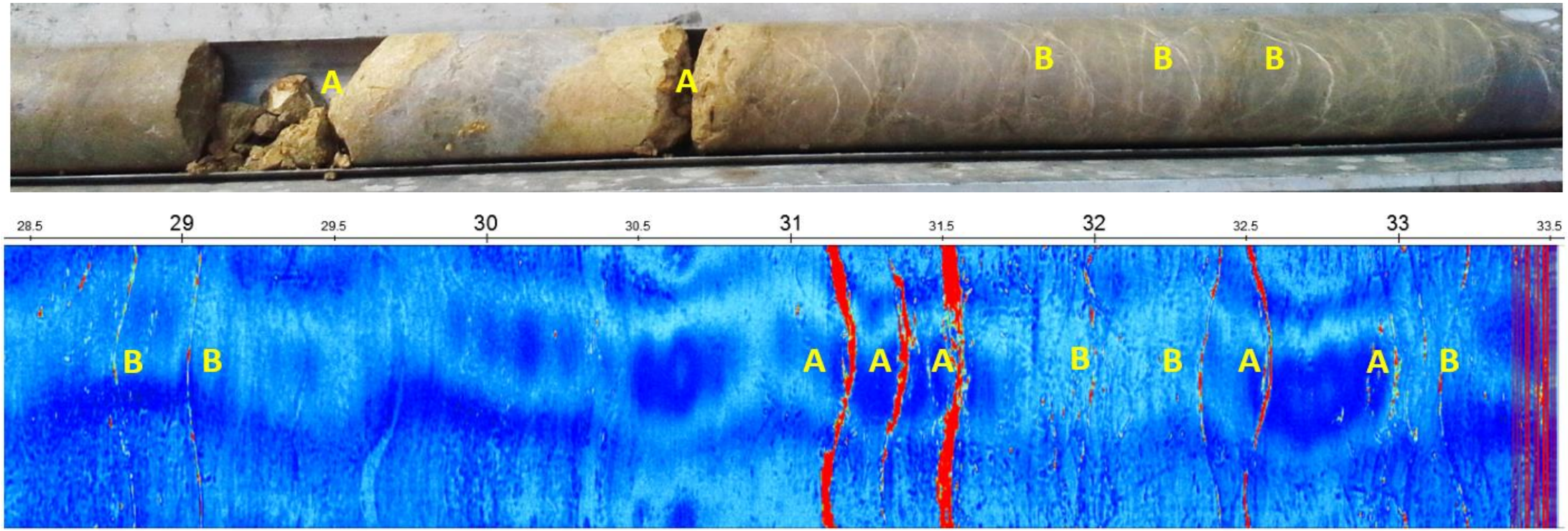




Louis C. (1967)
Strömungsvorgange in kluftigen Medien und ihre Wirkung auf die Standsicherheit von Bauwerken und Böschungen im Fels. Veröffentlichungen des Inst. für Boden- und Felsmechanik, Universität Karlsruhe, Heft 30.

ASSESSMENT OF THE DESIGN

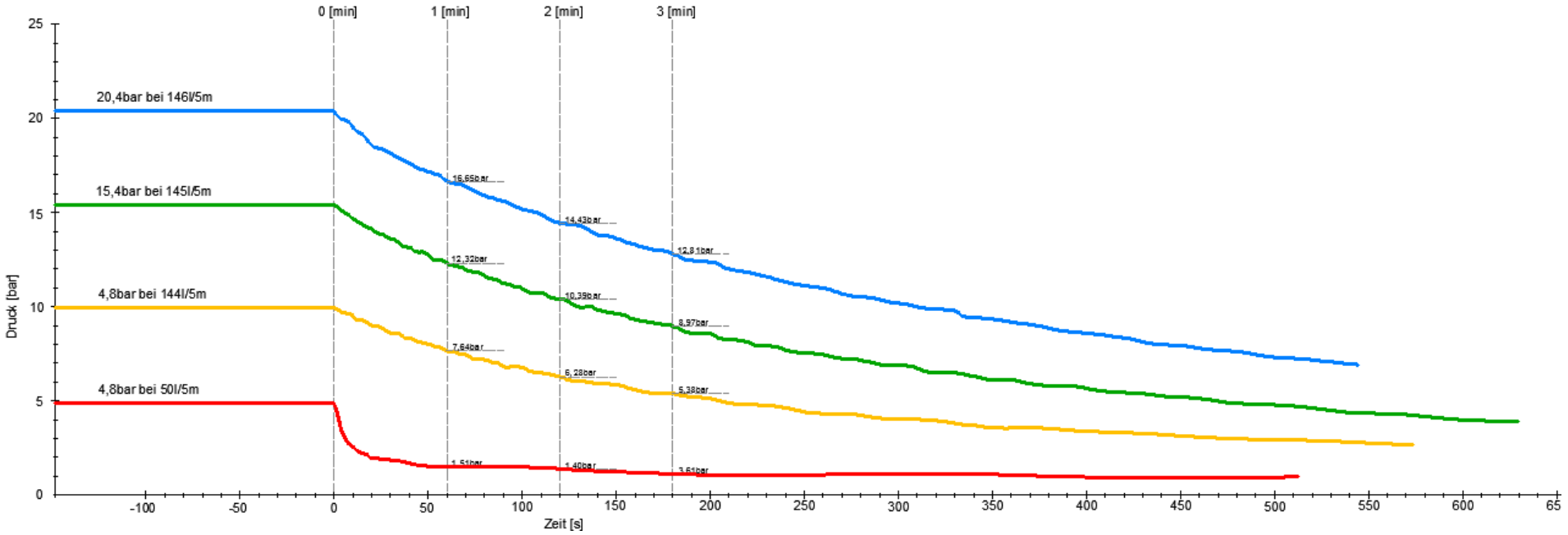
ONGOING GEOTECH INVESTIGATION REQUIRED



BAUSCHADENANALYSE PSPP
ASSESSMENT OF THE DESIGN

ROCK MASS RESPONSE WITH TPA INSTEAD OF G.I.N.

Versuchsfeld 2 / Tertiärbohrung / ~8,8Lugeon
2. Passe: 5 - 10 m
Rezept 6 (WZ 1,0; 1,0% Bentonit; 1,0% Plastifizierer)



BAUSCHADENANALYSE PSPP

ASSESSMENT OF THE DESIGN

. TRAVEL FORM WORK STABILITY ISSUES

. INSUFFICIENT DIMENSIONING

. LIMIT STATE INSTEAD OF ALLOWABLE DEFORMATION

. RECURRING FAILURES

_CONCRETE OUTFLOW

_INTERRUPTION OF CONCRETE WORKS

_CONCRETE SUPPLY CHAIN DISTURBANCIES

. VIBRATING ACTUATORS ON FORMWORK FOR SCC !?

BAUSCHADENANALYSE PSPP
ASSESSMENT OF THE DESIGN

CRITERIA	QUANTITY/QUALITY	ACCORDANCE WITH SPECIFICATIONS
Compressive Strength	50MPa	Yes
CEM I 52.5 N (kg)	460	Type and Quantity: Yes, min.: 320kg/m³
Coarse Aggregate (8-19 mm)	42%	-
Crushed Sand (0-5 mm)	38%	-
Natural Sand (0-2 mm)	20%	-
Superplasticizer	1.2% from cement weight	-
HGP Retarder	0.3% from cement weight	-
Water Proofing Admixture	0.5% from cement weight	-
Effective water (liter)	190	Yes: w/b ratio = 0.413
Water – Binder ratio 0.43		No: w/b ratio limited with 0.42
Slump	S7	-

?

BAUSCHADENANALYSE PSPP
ASSESSMENT OF THE DESIGN

CEM I 52,5 N – PORTLANDCEMENT (CaO, SiO_2, Al_2O_3, Fe_2O_3)

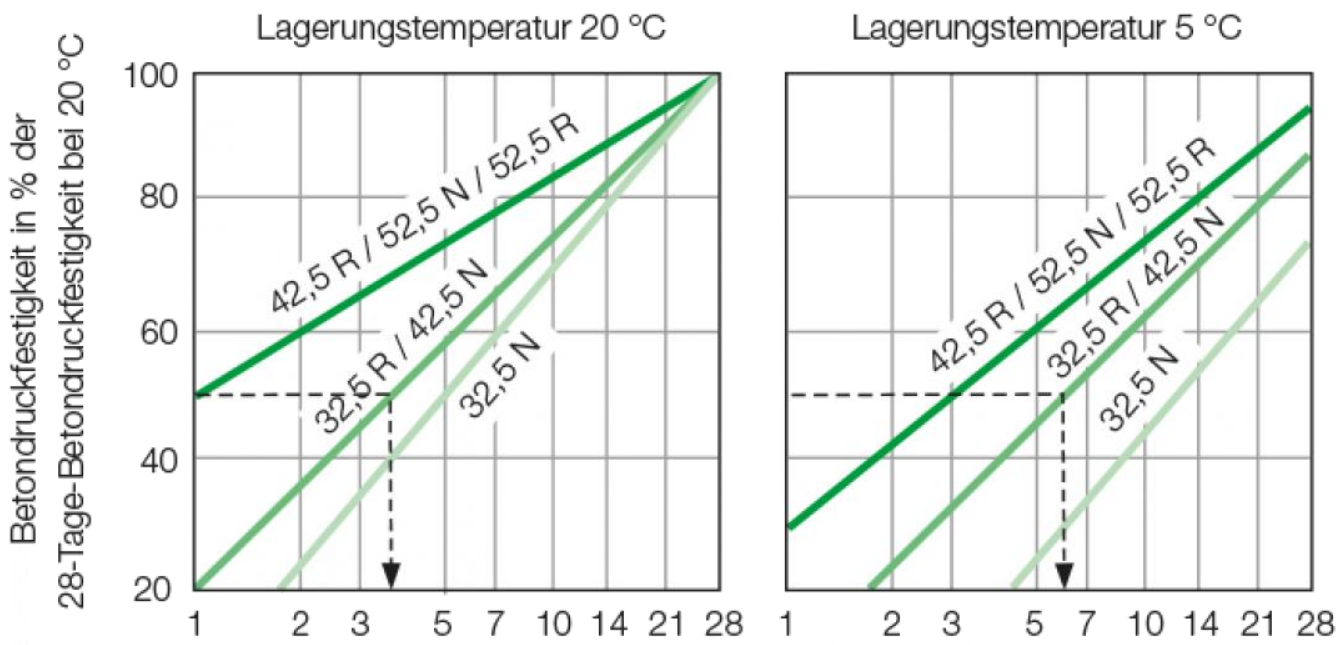
APPLICATIONS

. COMPRESSIVE STRENGTHS C30/37, C35/45, C45/55

. EARLY HIGH STRENGTH CONCRETE

. COLD WEATHER / COLD REGION (ANNUAL MEAN AVERAGE AT THE SITE: 26°C)

. PRESTRESSED APPLICATIONS (DIN 1045-1)



BAUSCHADENANALYSE PSPP
ASSESSMENT OF CONC. IMPLEMENTATION

Concrete Mix Stability

. With reference to own experience, international standards and guidelines such as

. Leaflet for Self Compacting Concrete (SCC) from Deutscher Beton- und Bautechnik-Verein

. Guidelines for massive Concrete Elements

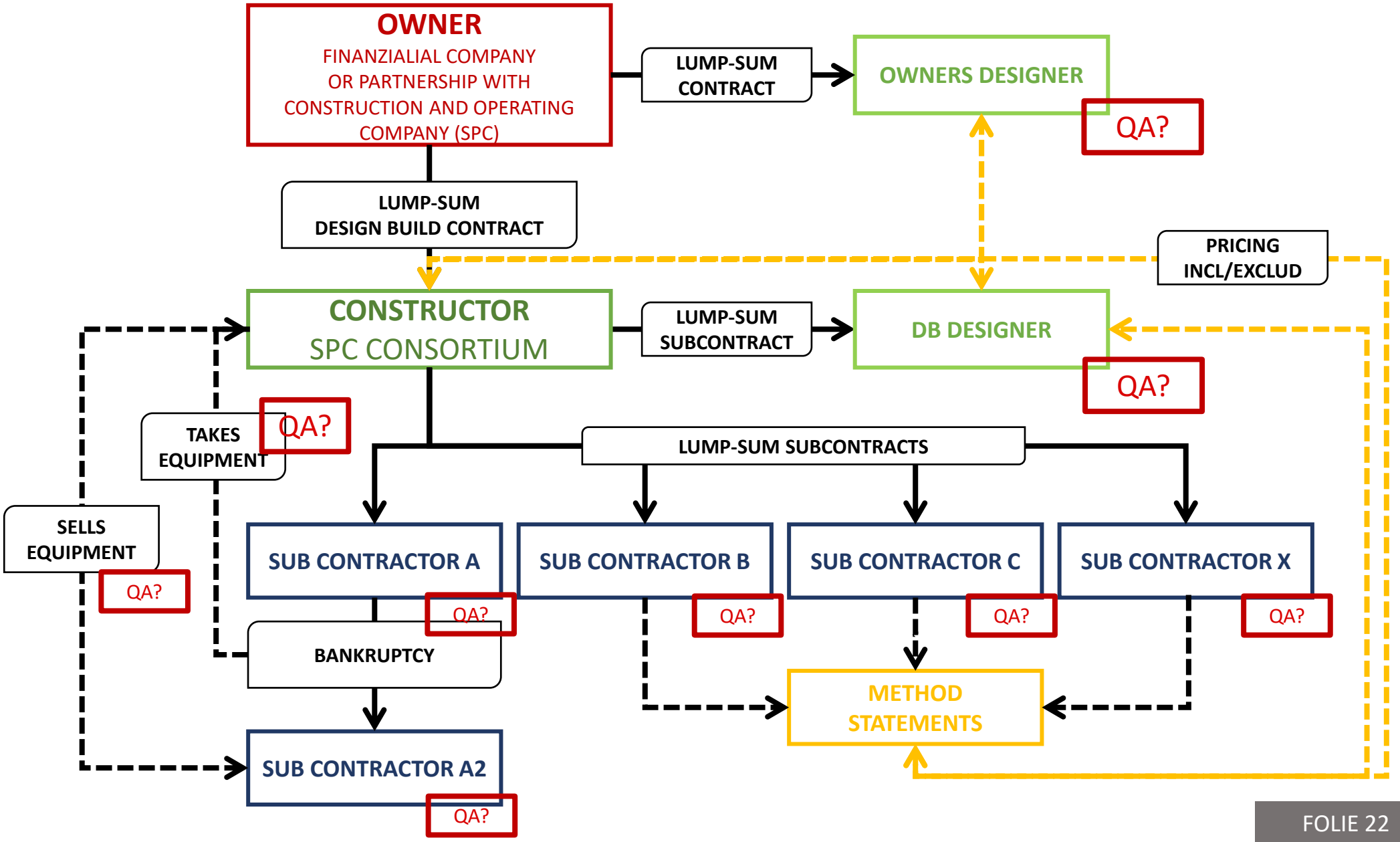
. Guidelines for waterproof Concrete Elements from Deutscher Ausschuss für Stahlbeton

…the concrete mix stability during pouring and concrete travel in the formwork is governed by the following aspects:

- content of ultra-fines
- overall grain size distribution of aggregates
- water/binder ratio and grinding fineness of the cement
- content and type of super plasticizer (SP)

Adjustments of the concrete mix considering these components would have avoided most of identified defects.

CONTRACT AND PROJECT CONFIGURATION



BAUSCHADENANALYSE PSPP

DEMINISHED VALUE ASSESSMENT

VALUE?

The value of an item of property is not an item related characteristic per se such as a physical characteristic which objectively exists. The value rather depends on a certain relationship between the person or institution who or which judges the good in a certain situation based on options the person or institution has in the moment of judgement.

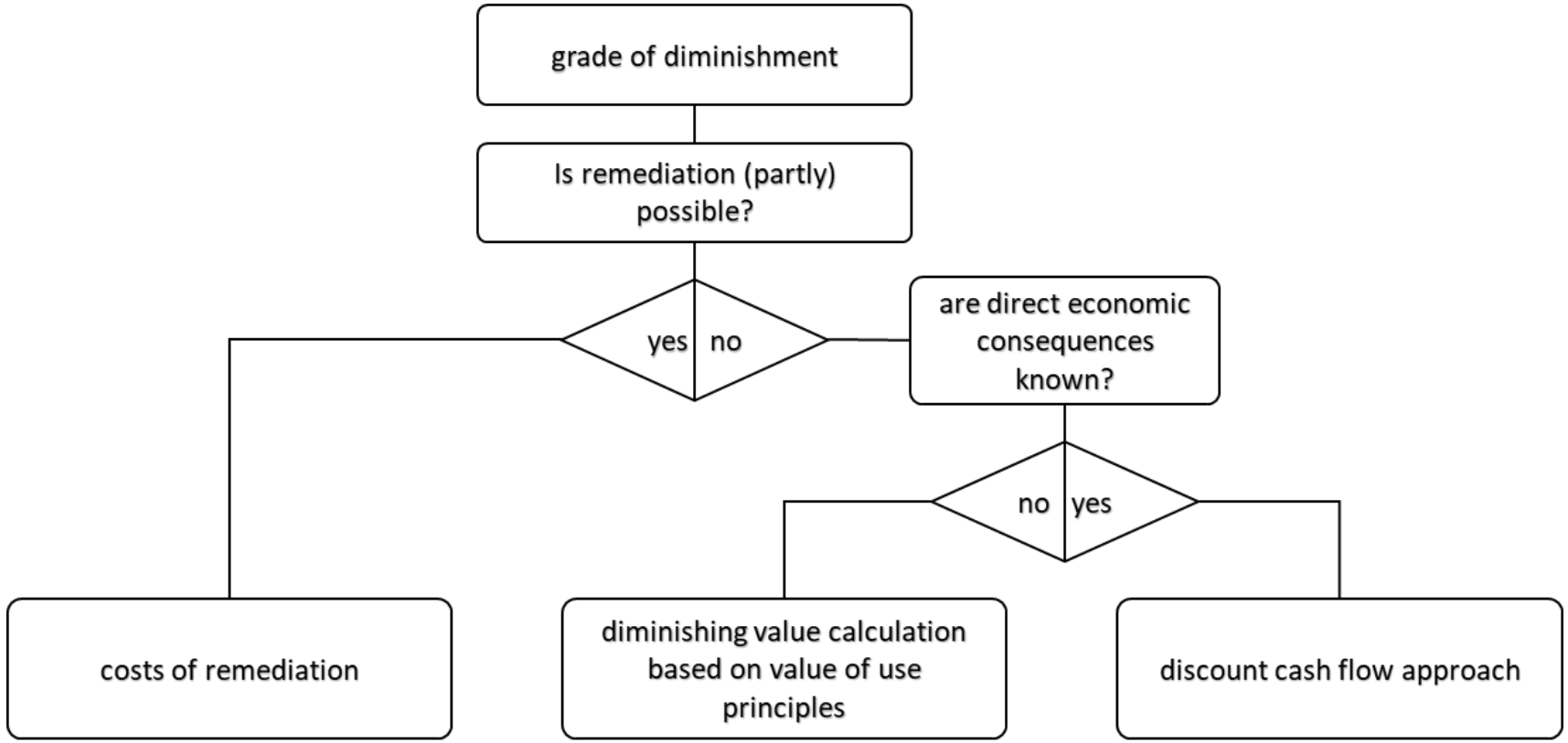
BAUSCHADENANALYSE PSPP
DEMINISHED VALUE ASSESSMENT

At the beginning of a diminished value assessment of a structure, **the value of the structure needs to be defined and determined**. Generally, the value of an object is **not necessarily equal to its price**, however, in many cases the price strongly affects the value. The following factors affect the value:

- **Usability in the economic sense**
  - Value in use or practical value
  - Extent of the preference for a potential exchange operation
  - Extent of the ability of a good to satisfy a need or another criterion
- For the grade or extent of usability five factors are relevant
    - The user,
    - The purpose of the good which is used,
    - The situation in which the good shall be used,
    - The time at which the good shall be used,
    - The good itself,
  - **Prestige value** and esthetical value (example: private rocket launches, e-car burn, first PSPP…)
- Rarity
- **Price**

DEMINISHED VALUE ASSESSMENT

WHICH METHOD TO DETERMINE THE DEMINISHED VALUE IS ADEQUATE?



adapted after Fillibeck, R

BAUSCHADENANALYSE PSPP
DEMINISHED VALUE ASSESSMENT

WHICH METHOD TO DETERMINE THE DEMINISHED VALUE IS ADEQUATE?

CARDINALE SCALAR FOR JUDGMENT	DEVIATION FACTOR
NOT USABLE	10
INADEQUATE BUT USABLE TO A VERY LIMITED DEGREE	9
VERY DEFICIENT	8
DEFICIENT	7
PARTLY DEFICIENT	6
NOT ACCEPTABLE	5
PARTLY NOT ACCEPTABLE	4
MARGINALLY ACCEPTABLE	3
(PARTLY) NEGATIVELY AFFECTED	2
ALMOST NOT AFFECTED	1
PERFECT	0

JUDGEMENT CRITERIA	WEIGHTING (GI)	DEVIATION FACTOR (AI)	SUBTOTALS (GI*AI)/10
OVERALL FUNCTIONALITY	65	8	52
LONG TERM STABILITY	15	8	12
LONG TERM PERFORMANCE	10	9	9
EFFICIENCY	5	3	1.5
PLANT SAFETY	2.5	3	0.75
DAMAGE OF EPC REPUTATION	2.5	8	2
	100	PERCENTAGE OF TOTAL DIMINISHED VALUE	77.25%

BAUSCHADENANALYSE PSPP

DEMINISHED VALUE ASSESSMENT

LESSONS TO BE LEARNED

. THE METHOD TO DETERMINE THE DEMINISHED VALUE SHALL BE DEFINED PRIOR TO THE WORK

_to be defined in the construction contract or DB contract.

_directly interconnected with quality or performance criteria.

. Hold back and bank guarantees must be implemented when the owner has not the capacity or the contractual framework to solve bankruptcies of contractors or sub-contractors.

. Sub-contracting must be ruled out for critical deliverables and critical disciplines.

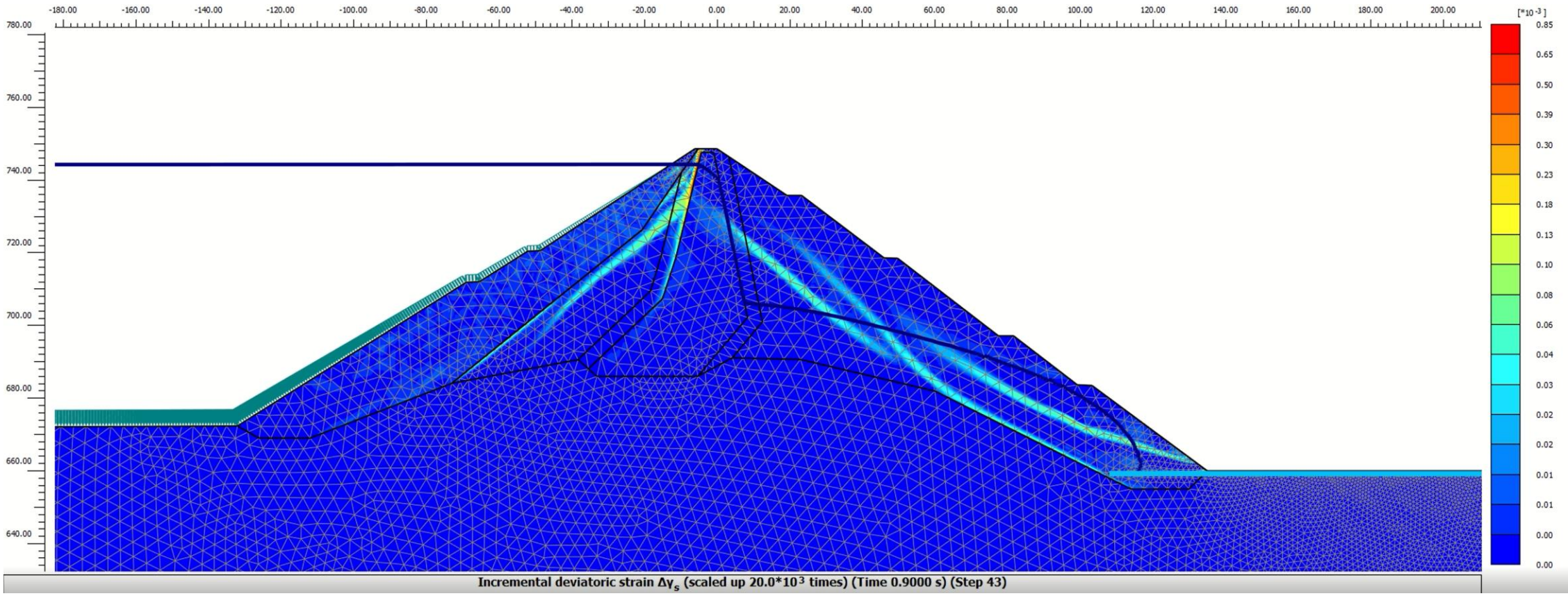
. Contractor selection for critical deliverables and disciplines must be primarily based on real technical and financial performance criteria.

. Owners Engineers, Contractor Engineers as well as QA Engineers and site inspection must be contracted independently with sufficient financial recourses to assure high level design, required design adjustments and high level QA throughout the entire project.

. DON'T PUT MORE PRESSURE OF TIME ON A PROJECT THAN ABSOLUTELY REQUIRED

. ESTABLISH A CULTURE OF OPEN ERROR DISCUSSION AND ERROR COMMUNICATION

ERDBEBENVERHALTEN VON DÄMMEN



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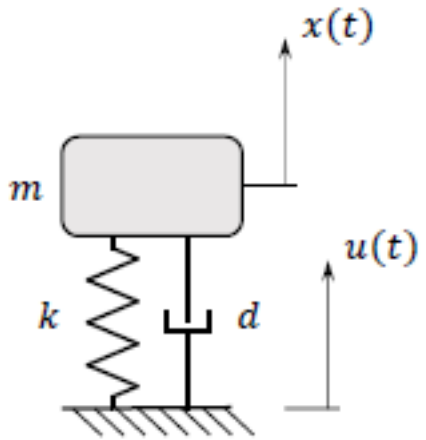
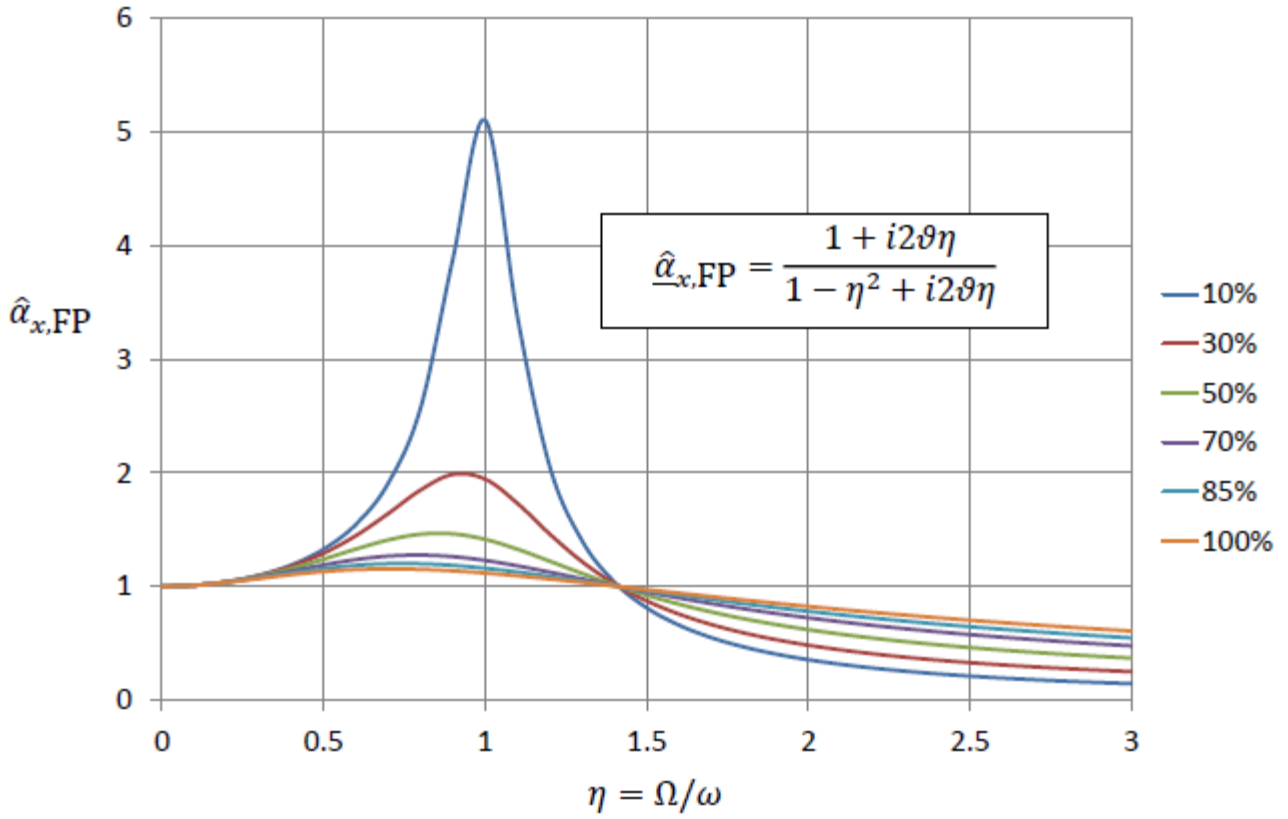
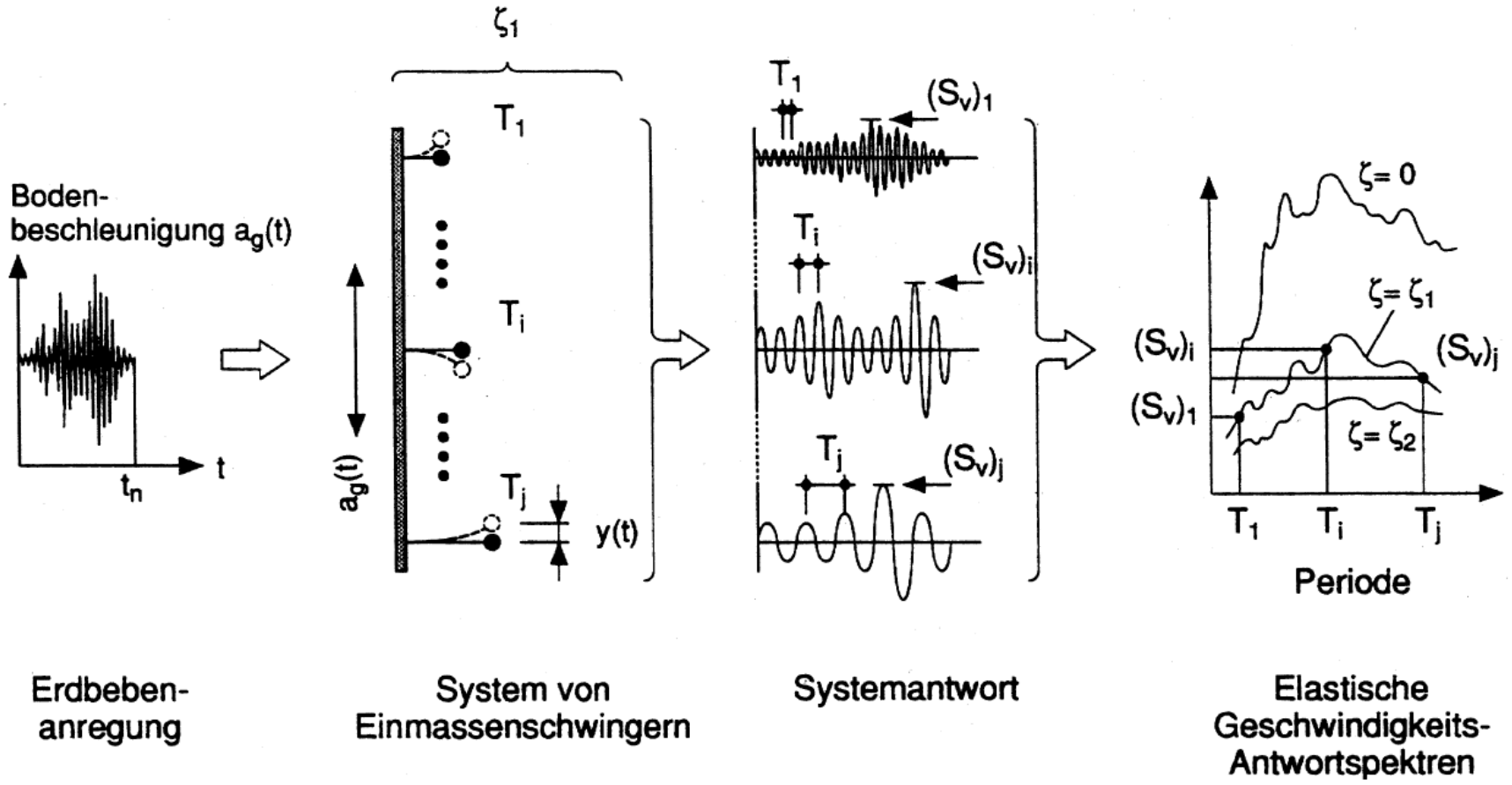




ERDBEBENVERHALTEN VON DÄMMEN

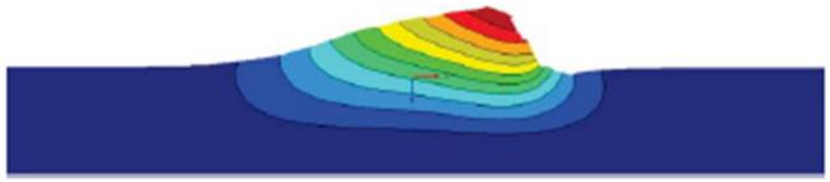
ERDBEBENANREGUNG UND ANTWORTSPEKTREN



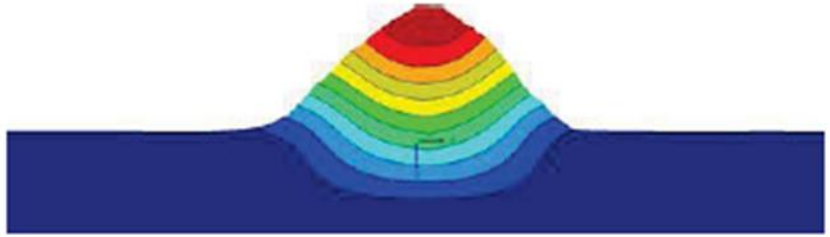
Bachmann (2002)

ERDBEBENVERHALTEN VON DÄMMEN

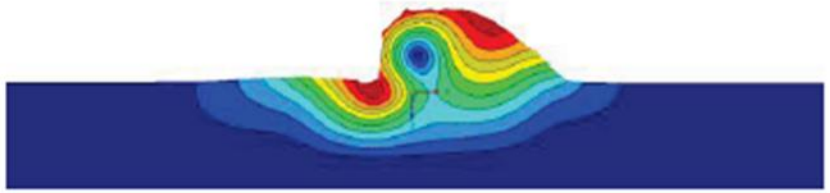
EIGENFORMEN



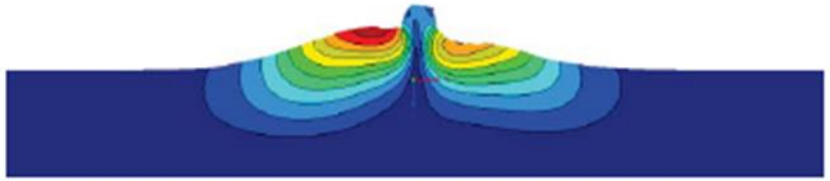
1. Eigenform



2. Eigenform



3. Eigenform

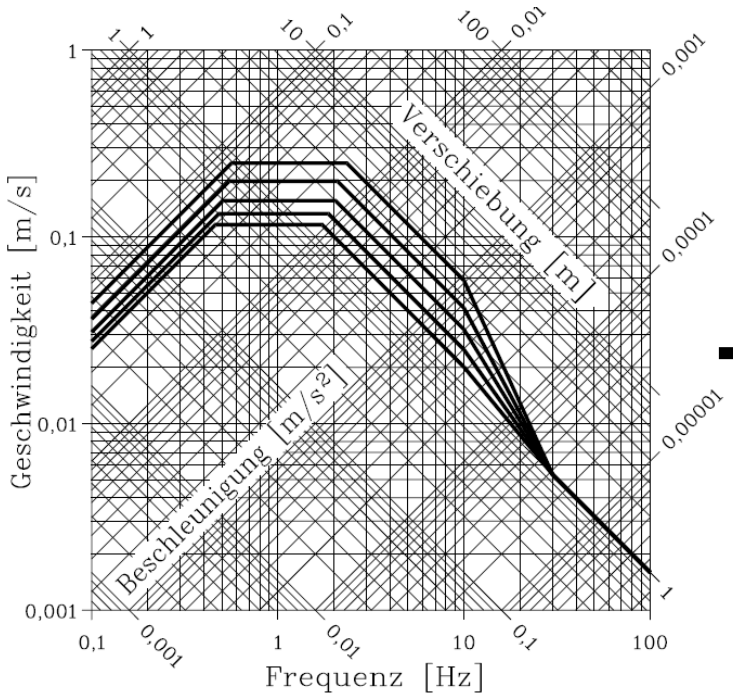


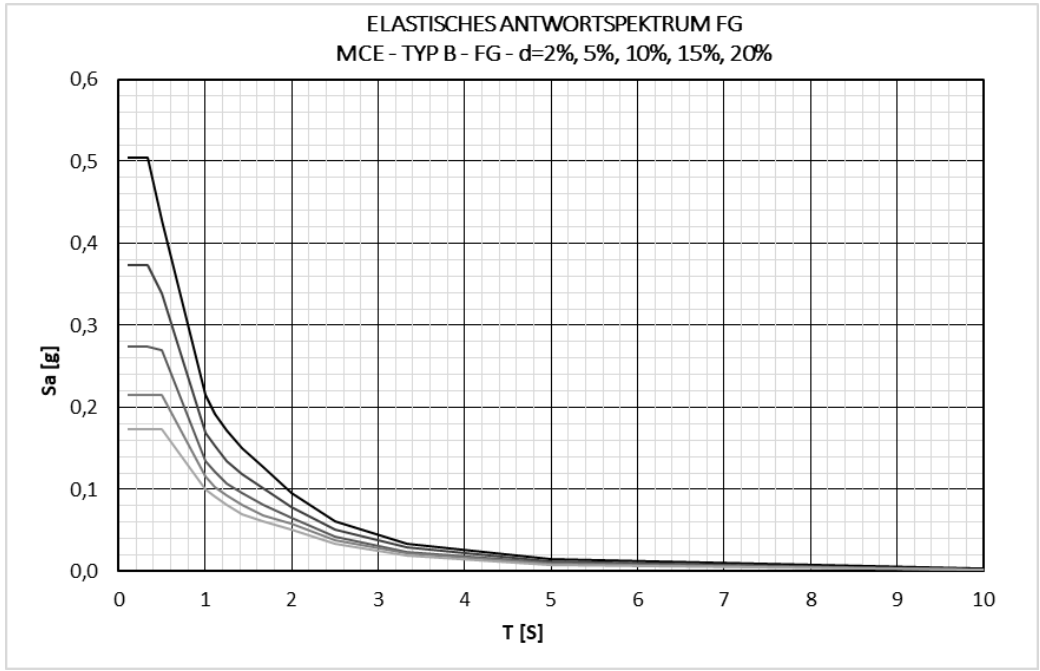
4. Eigenform

Schulz 2013

ERDBEBENVERHALTEN VON DÄMMEN

VORGABEN GEMÄSS ERDBEBENRICHTLINIE FÜR STAUDÄMME





A. ABLEITEN DES BEMESSUNGSSPEKTRUMS AUS DEM NORMSPEKTRUM GEMÄSS RICHTLINIE STAUBECKENKOMMISSION FÜR VERSCHIEDENE UNTERGRUNDARTEN UND ERDBEBENZONEN MIT ENTSPRECHENDEN VERGRÖSSERUNGSFUNKTIONEN
B. ABLEITEN DES ELASTISCHEN ANTWORTSPEKTRUMS NACH NEWMARK

ERDBEBENVERHALTEN VON DÄMMEN

METHODEN UND EINSCHRÄNKUNGEN
DYNAMISCHES NÄHERUNGSVERFAHREN

$$G_{\max} = \rho v_{\max}^2 \qquad \omega_n = \beta_n \upsilon_s / H$$

$$\ddot{u}(y,t) = \sum_{n=1}^{\infty} \frac{2J_0(\beta_n y/h)}{\beta_n J_1 \beta_n} \omega_n v_n(t)$$

$$J_0(\omega h\sqrt{\rho/G}) = 0$$

$$\phi_n(y) = \frac{2J_0(\beta_n y/h)}{\beta_n v_1(\beta_n)}$$

Spektraler Wirkfaktor
„mode participation factor“

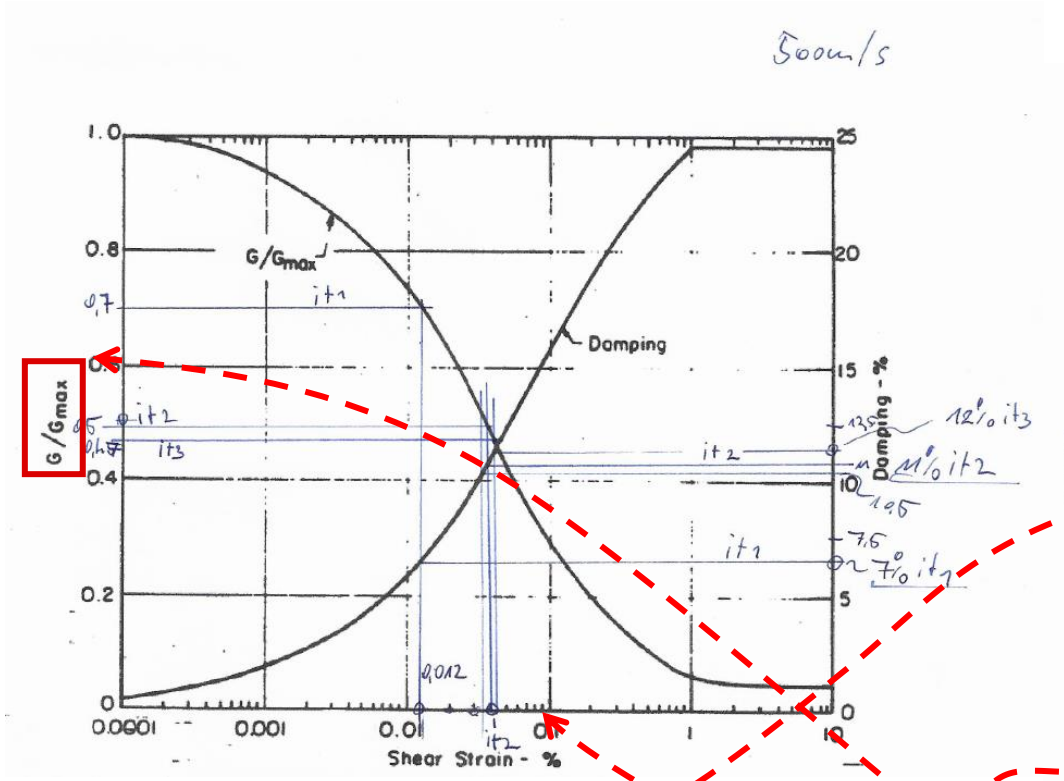
$$\ddot{u}_n(0,t) = \phi_n(0) Sa(t)$$

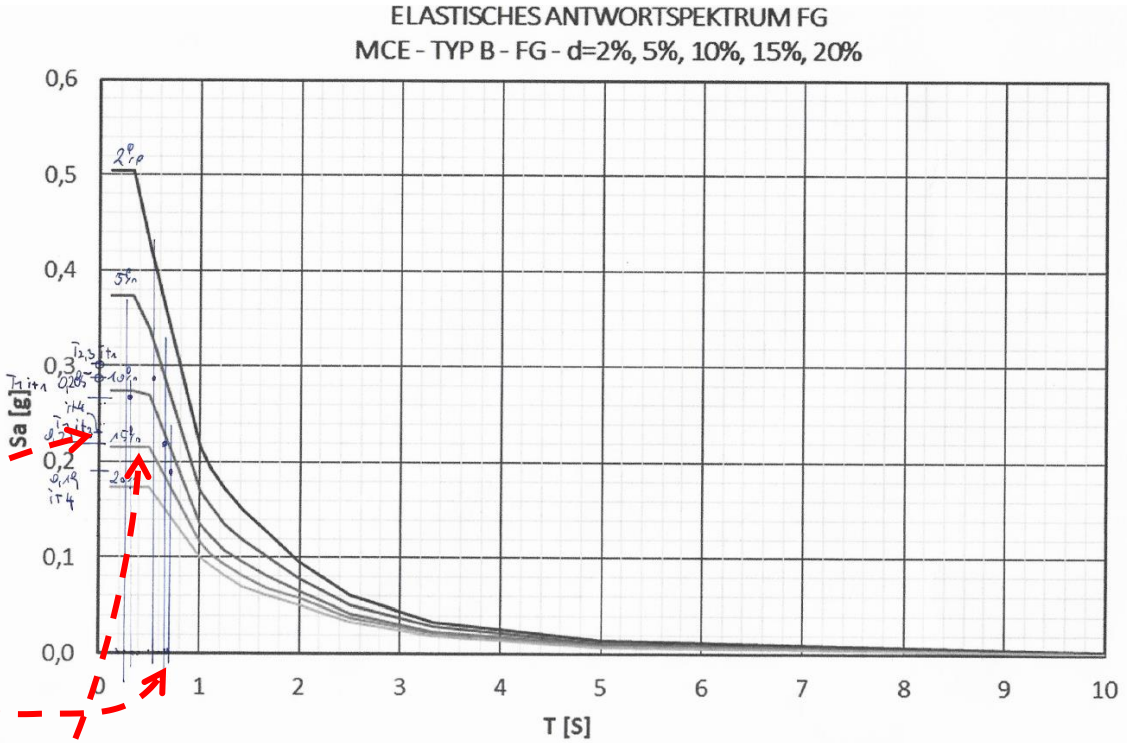
Formelwerk Makdisi & Seed
in guter Übereinstimmung mit Monobe und Gazetas

ERDBEBENVERHALTEN VON DÄMMEN

METHODEN UND EINSCHRÄNKUNGEN

DYNAMISCHES NÄHERUNGSVERFAHREN





$$\ddot{u}_{n_{max}} = \phi_n(0)\, s_{an}$$

$$\ddot{u}_{max} = \left[\sum_{n=1}^{3} (\ddot{u}_{n_{max}})^2\right]^{1/2}$$

$$\omega_n = \beta_n v_s / H$$

$$(\gamma_{ave})_{max} = \frac{h}{v_s^2} (\phi_1')_{ave}\, s_{a1}$$!

ERDBEBENVERHALTEN VON DÄMMEN

METHODEN UND EINSCHRÄNKUNGEN
DYNAMISCHES NÄHERUNGSVERFAHREN

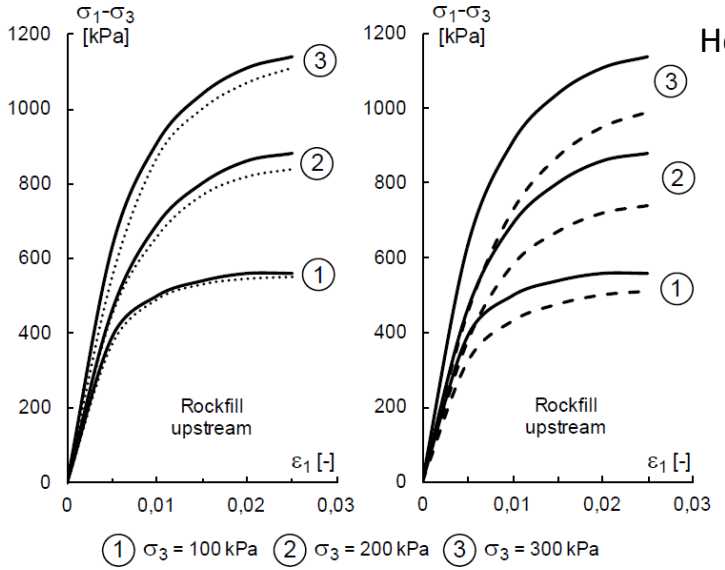
IDEE DES VERFAHRENS

EIN DREICKIGER DAMMKÖRPER MIT UNENDLICHER LÄNGE ERFÄHRT EINE FUSSPUNKTERREGUNG

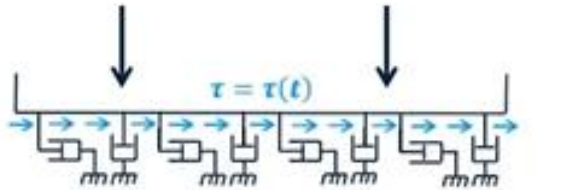
- GEOMETRIE LÄSST KEINE BIEGEMOMENTE ZU -> BREITE AUFSTANDSFLÄCHE
- IDEAL ELASTISCH
- INFINITER SCHERWIDERSTAND FÜR DIE BERECHNUNG DER KRONENBESCHLEUNIGUNG
- MEHRMASSENSCHWINGER MIT HÖHENABHÄNGIGER ANTWORT
- UNTERSUCHUNG DER DREI ERSTEN EIGENFORMEN
- DÄMPFUNG ABHÄNGIG VON DER SCHUBVERZERRUNG

ERDBEBENVERHALTEN VON DÄMMEN

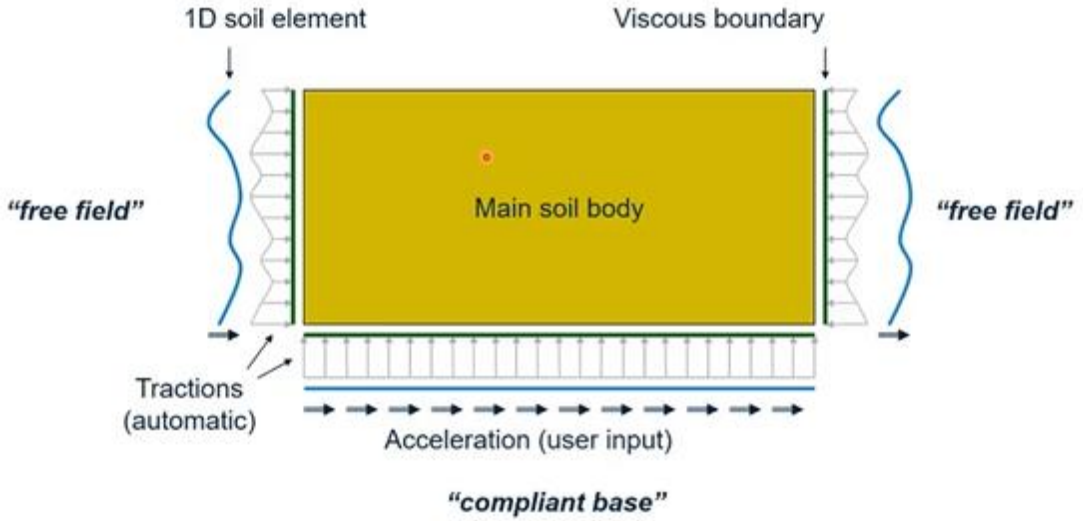
EINFLUSS DER AUFSTANDSTOPOGRAPHIE
STOFFMODELLE UND MODELL RANDBEDINGUNGEN

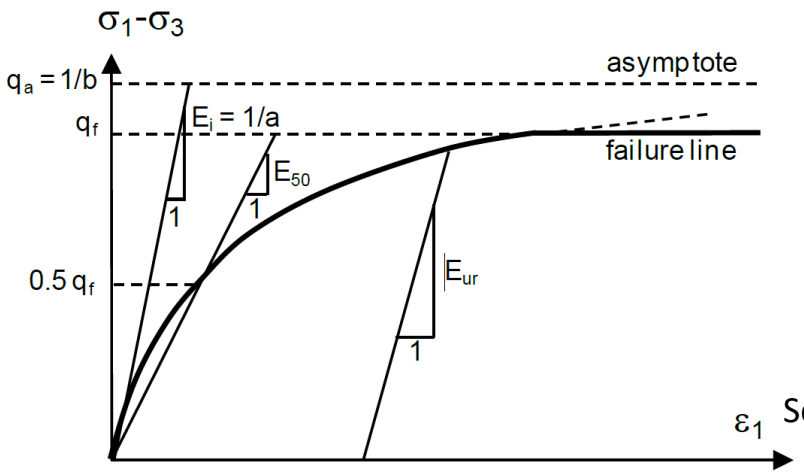


Holzmann et. al. 2008



Compliant base
No reflection
Incoming waves: signal requires upward motion only





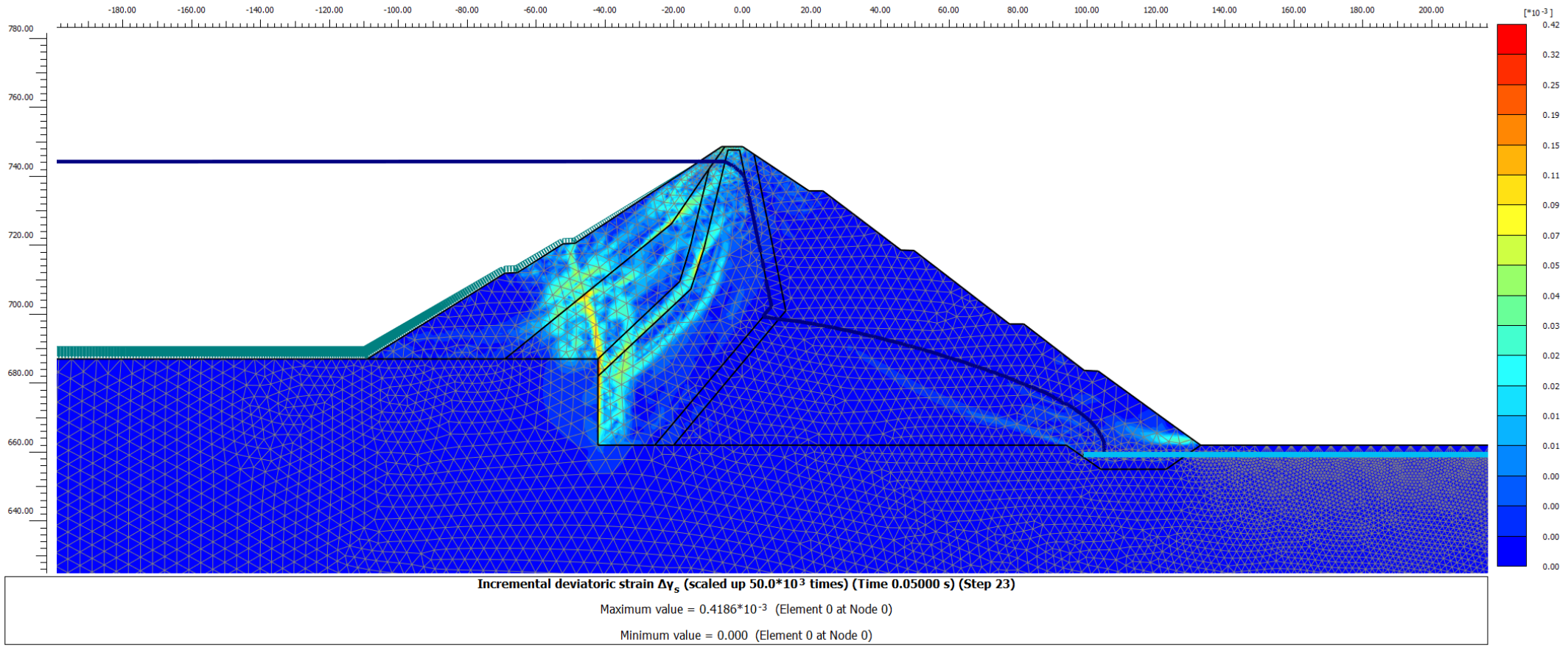
Schanz et. al. 1999

ERDBEBENVERHALTEN VON DÄMMEN

EINFLUSS DER AUFSTANDSTOPOGRAPHIE

FE ANALYSE

FALL A - STUFE

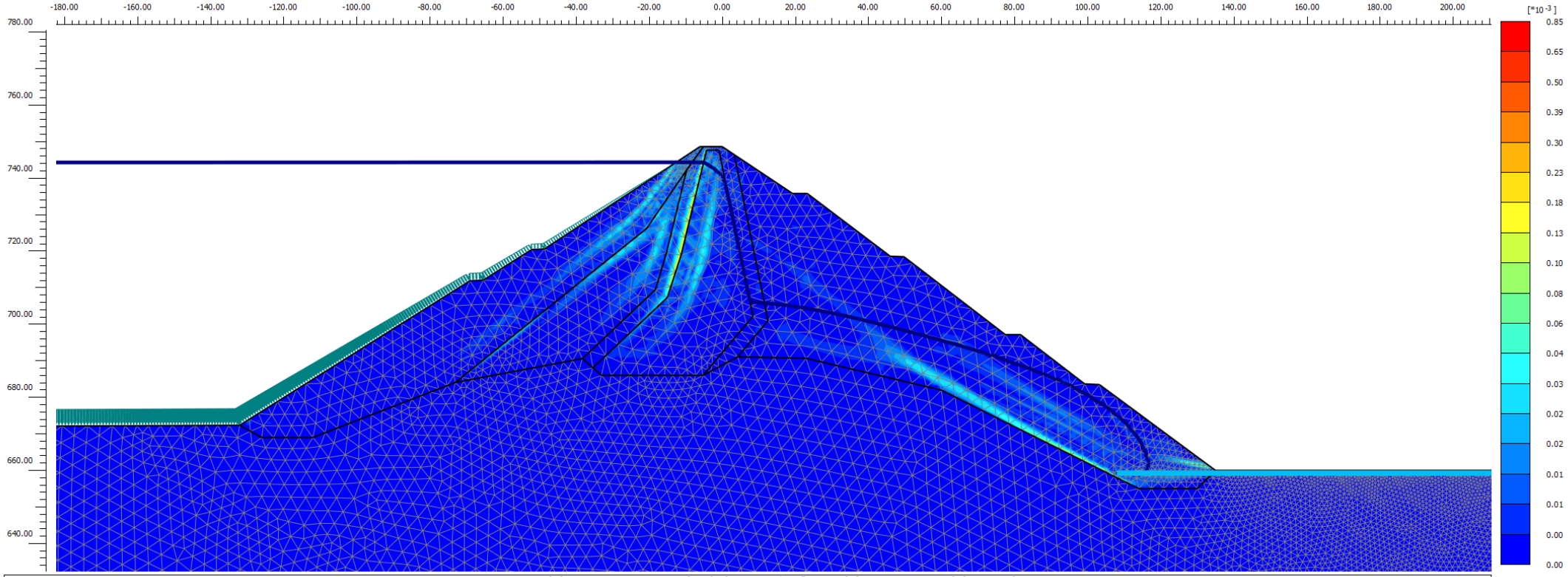


ERDBEBENVERHALTEN VON DÄMMEN

EINFLUSS DER AUFSTANDSTOPOGRAPHIE

FE ANALYSE

FALL B - KUPPE



ERDBEBENVERHALTEN VON DÄMMEN

EINFLUSS DER AUFSTANDSTOPOGRAPHIE

FE ANALYSE

FALL C - EBENE