Structural Civil Protection

Eartquake-Resistant Construction

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Duty of Architects and Civil Engineers

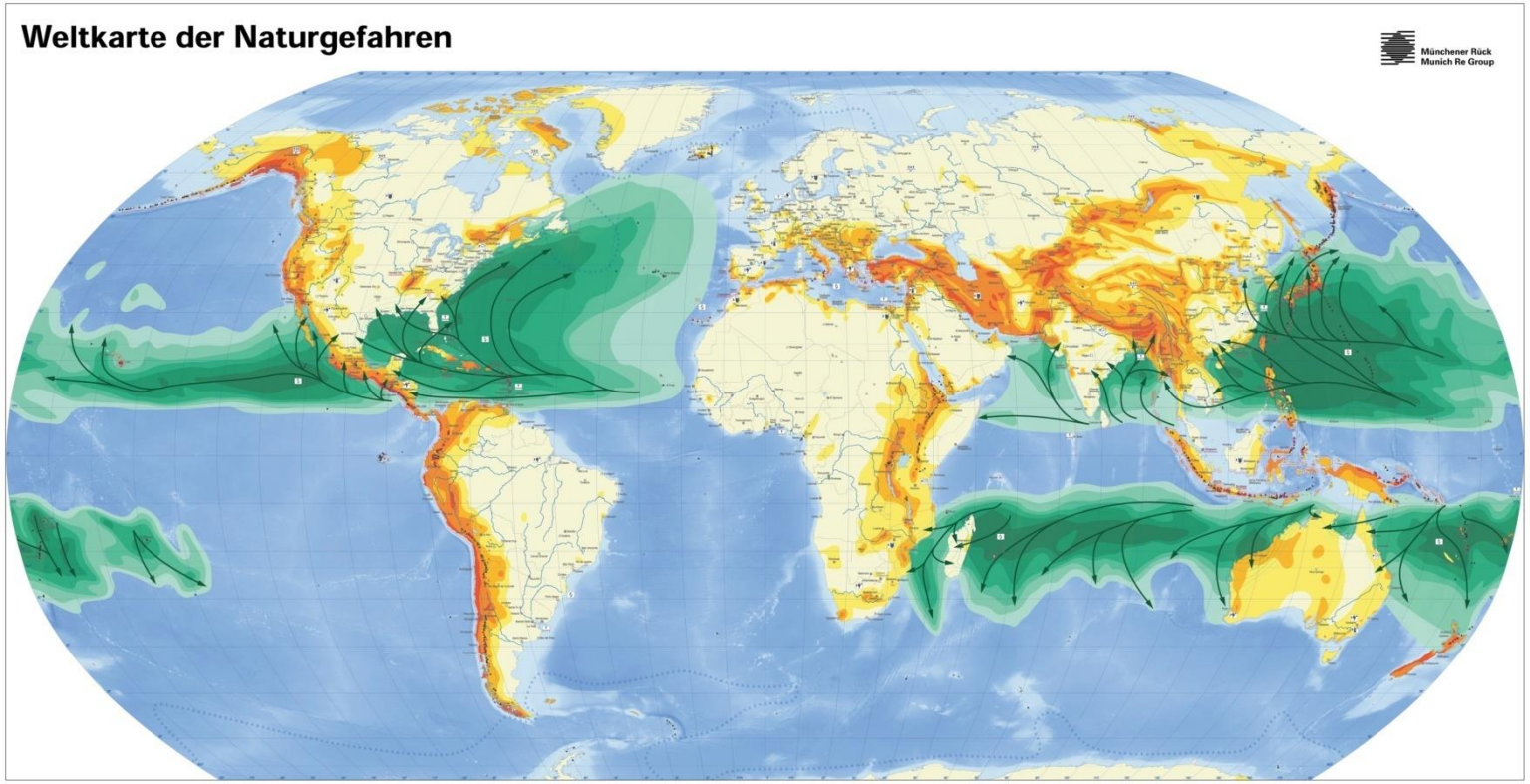
Ensure **safety**
of the **built infrastructure**
in order to **avert danger to life and physical integrity**
against ordinary and exceptional actions (GG Art.2 Abs 2, MBO, LBO, §249 StGB).

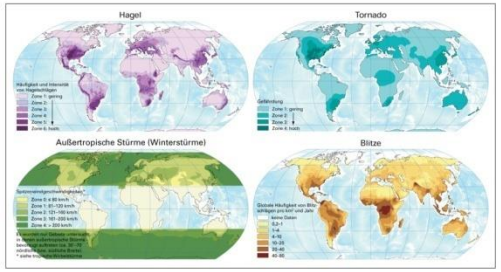
What level of **safety** is **accepted** by society and **affordable**?
Safety – **Risk** are **relative**!

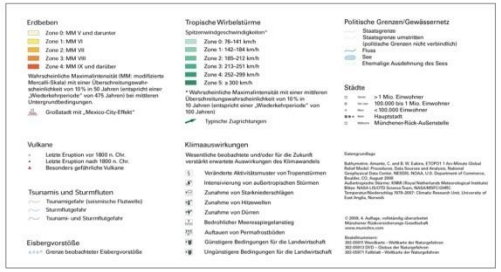
Nature!
Hazard?

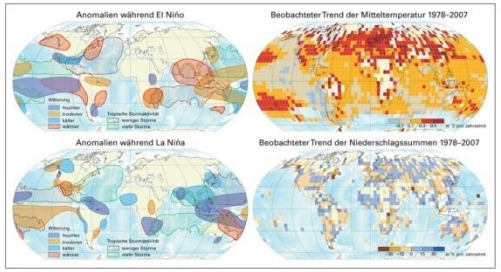
„There are deadly things in nature; dangers she prepares for me.
But there is nothing impure in it.“ Preach of Mathew 15:18

Natural hazards – Natural disasters









In GER:

- Floods
  - Inland floods
  - Flash floods
  - Storm surges
- Storms
  - Hurricanes
  - Tornados
- Hail
- Snow
- Thunderstorm
- Avalanche
- Rock fall
- Land slide
- Earthquake
- Drought
- Heat
- Wildfire

- With regard to the "**human being as an object of protection**", the risk of death in Germany with regard to floods - flash floods / extreme storms / earthquakes is about 1.000 / 100 / 1!!!
- Most of the **natural disasters are caused by us humans**. Because we settle there, where there has always been natural hazards. We expose ourselves to the danger. Only through this the risk arises (R = P x L (R=Risk, P=probability, L=loss)) and thus the catastrophe.
- **Nature always behaves naturally**. It cannot do anything else. Consequence: We do not live in harmony with nature.

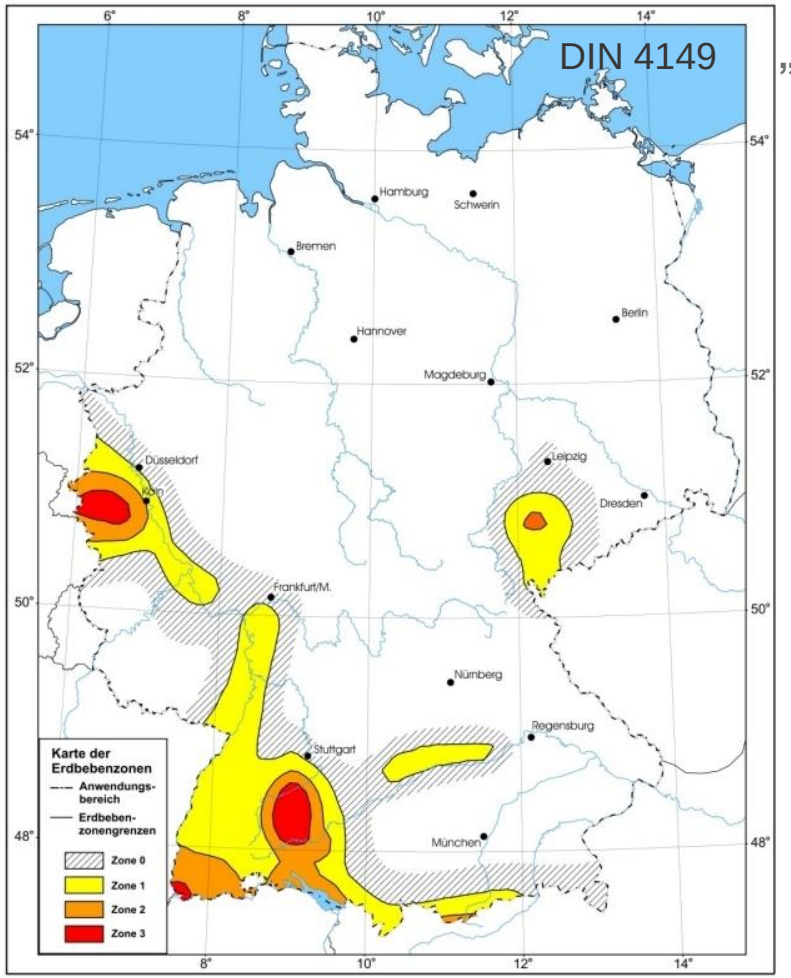
- Demand: Settlement bans after destructive catastrophes and for natural hazard prone areas (especially water, earthquakes (storm is different)) according to the hazard maps:
  - Eschenlohe (Alpine flood 2005)
  - Ahr valley (Flash flood 2021)
  - East Anatolian Fault (Earthquake 2023)
  - …

The Role of the Media – they have responsibility of correct information:

“Here is the environment most hostile” – what an ignorant statement!

Earthquakes

Earthquake – strong intensification of loads and extended zones

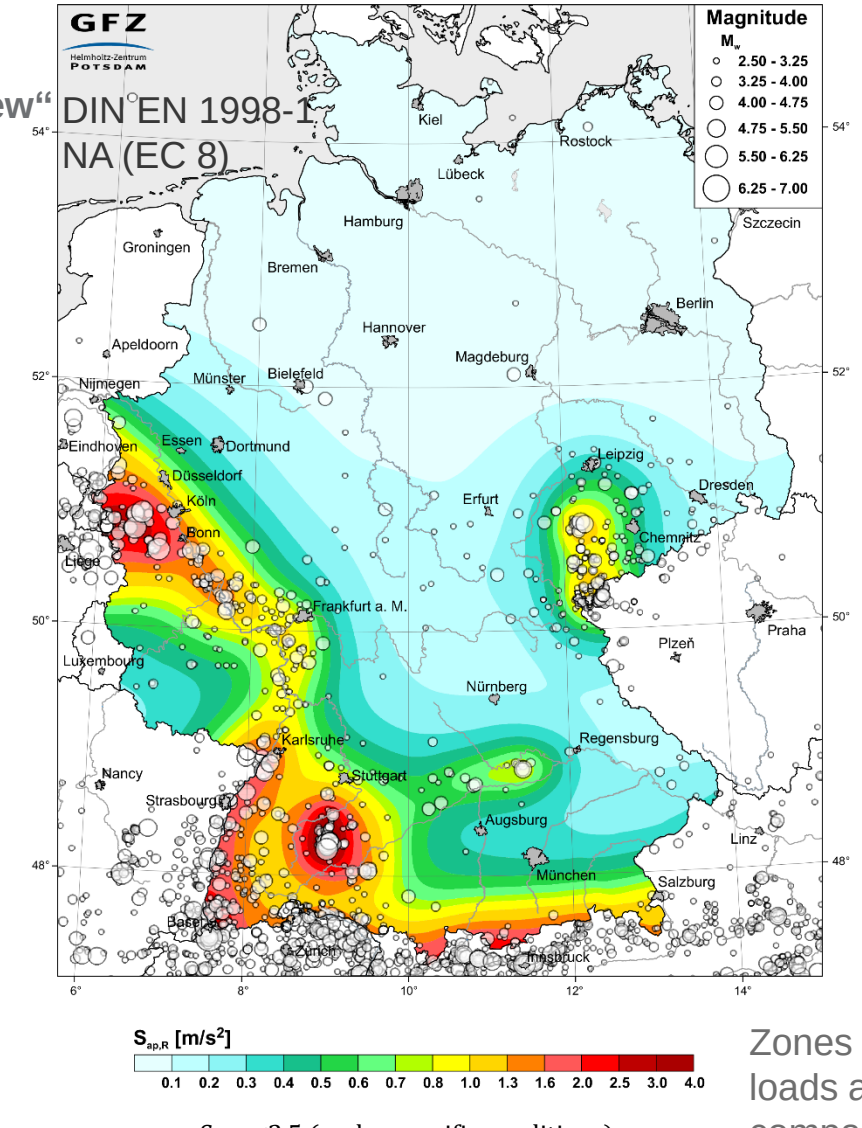


„today“

Bodenbeschleunigung zu den Erdbebenzonen

Erdbebenzone	Intensitätsintervalle	Bemessungswert der Bodenbeschleunigung a_g m/s²
0	$6 \le I < 6{,}5$	–
1	$6{,}5 \le I < 7$	0,4
2	$7 \le I < 7{,}5$	0,6
3	$7{,}5 \le I$	0,8

„new“



$a_g = S_{aP,R} / 2{,}5$ (under specific conditions)

Zones are expanded loads are doubled compared to DIN 4149

Earthquake – PGA determination

DIN 4149 German earthquake code – **valid only in GER**

Tabelle 2 — Zuordnung von Intensitätsintervallen und Bemessungswerten der Bodenbeschleunigung zu den Erdbebenzonen

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3	$7{,}5 \le I$	0,8

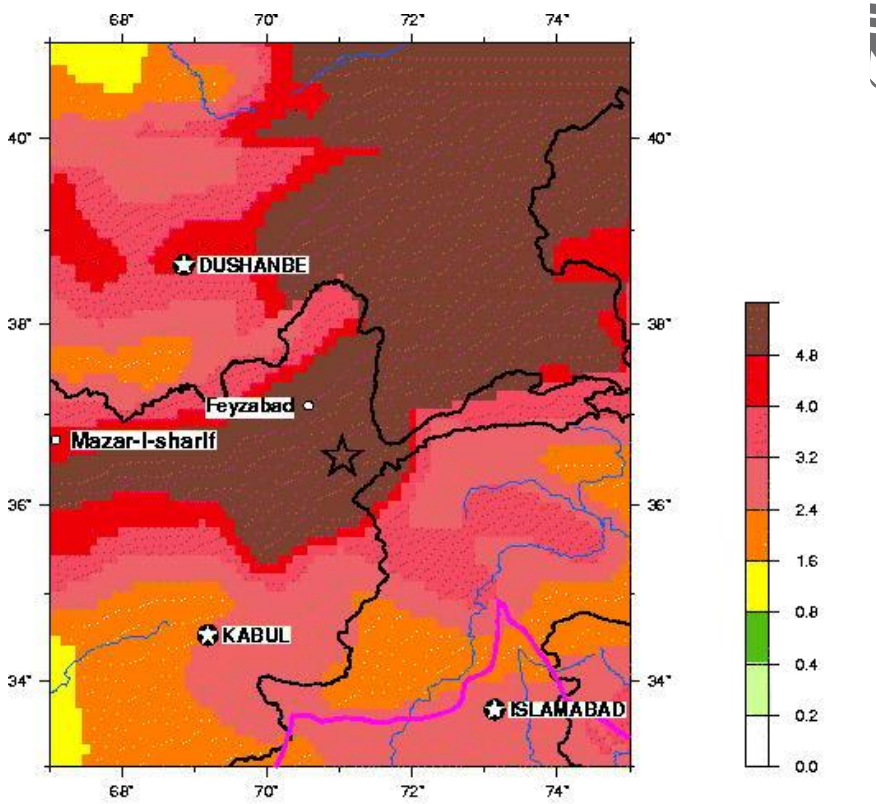
EC 8: no PGA data > international data bank > USGS, GFZ

PGA-Werte nach GSHAP			
Land	**Dienstort**	**PGA**	**Zone**
Afghanistan	Faisabad	8,6	III
Afghanistan	Herat	2,2	II, T.2
Afghanistan	Kabul	2,5	II, T.1
Afghanistan	Kunduz	5,3	III
Ägypten	Alexandria	0,7	I
Ägypten	Kairo	1,2	II, T.3
Ägypten	Theben	0,6	I

German zones are different from int. zones!!!

In one specific zone the PGA vary!

The Afghanistan experience (2007)



HINDU KUSH REGION, AFGHANISTAN

2004 04 05 21:24:04 UTC 36.53N 71.03E Depth: 191.4 km, Magnitude: 6.6

Peak Ground Acceleration (m/s²) with 10% Probability of Exceedance in 50 Years

Major Tectonic Boundaries: Subduction Zones -purple, Ridges -red and Transform Faults -green

USGS National Earthquake Information Center

Interim result

- ✓ German earthquake zones apply only to Germany.
- ✓ German earthquake zones have nothing to do with international earthquake zones.
- ✓ Tenders that specify seismic zones are useless, more, they show lack of knowledge.
- ✓ Earthquakes are independent of climate change.
- ✓ Avoid settling near tectonic boundaries. Exposing oneself to danger results in risk and therefore possibly in disaster.
- ✓ Strong intensification of earthquake loads and extension of zones in GER (2023?), although there is no reason due to lack of safety. >> Building will be more expensive (up to 10% of load-carrying construction). >> legal aspects for consulting engineers: Advice owners that a change is about to come?!

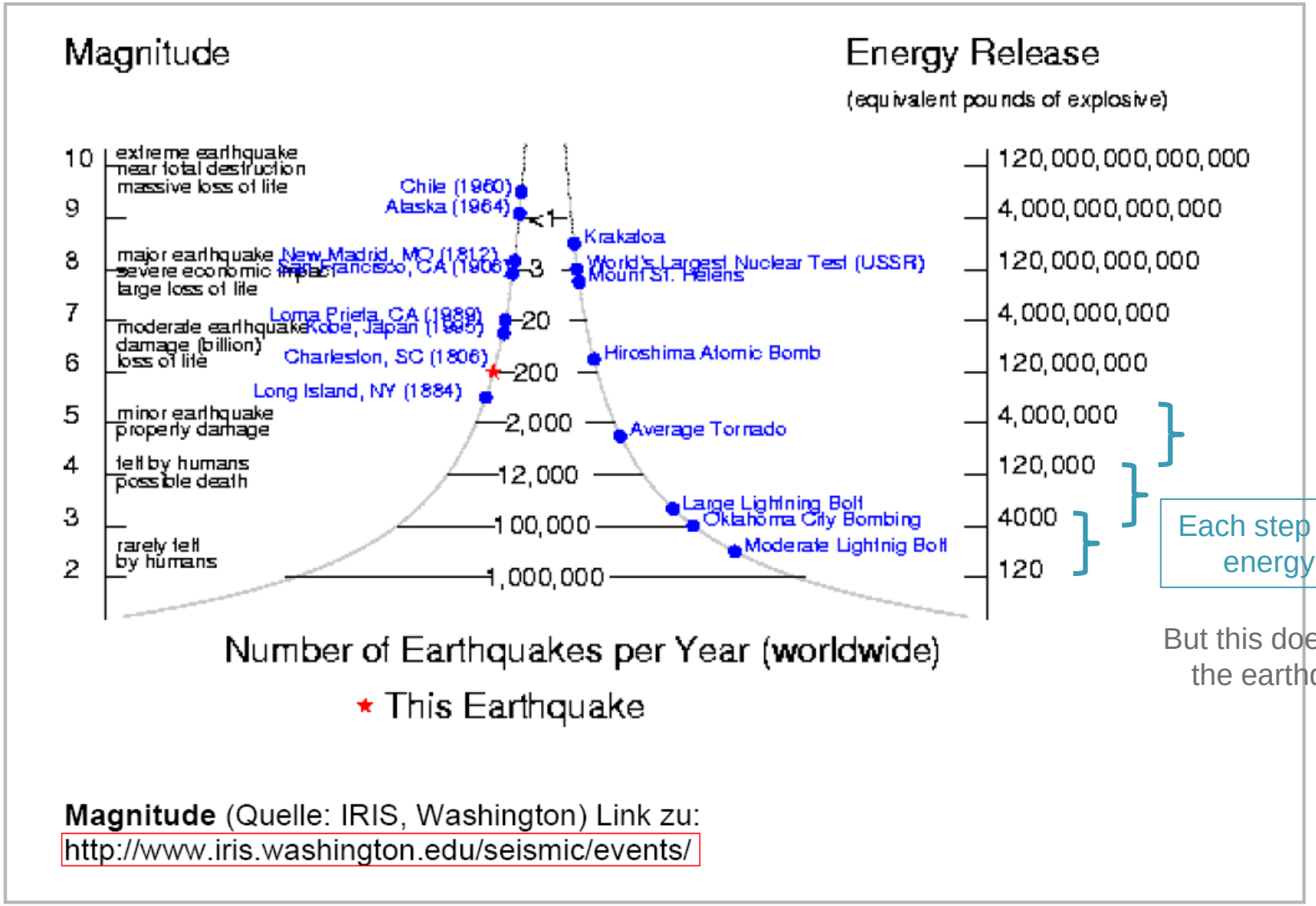
Earthquakes Basics

Assessment of earthquakes:

- Magnitudes
- Intensities

The **Richter magnitude scale** was developed by Charles Richter in partnership with Beno Gutenberg in 1935. They designed a scale to **measure the strength of earthquakes**. The Richter Scale is a 10 logarithmic scale, which means that a 5.0 magnitude earthquake is ten times larger than a 4.0 magnitude earthquake. The magnitude of an earthquake is calculated by the amplitude of waves, measured by using a seismograph. In combination with geophysical models the **earthquake energy release** can be estimated. One scale step means the 30 fold energy release.

Intensity is a measure of the **impact of earthquakes**, which is in contrast to the instrumentally determined **Magnitude.** The intensity is determined on the basis of the effects of an earthquake on landscape, roads or buildings communicated by people or satellite images. Depending on local conditions, a single earthquake classified according to one of the different scales may have different intensities at different locations.

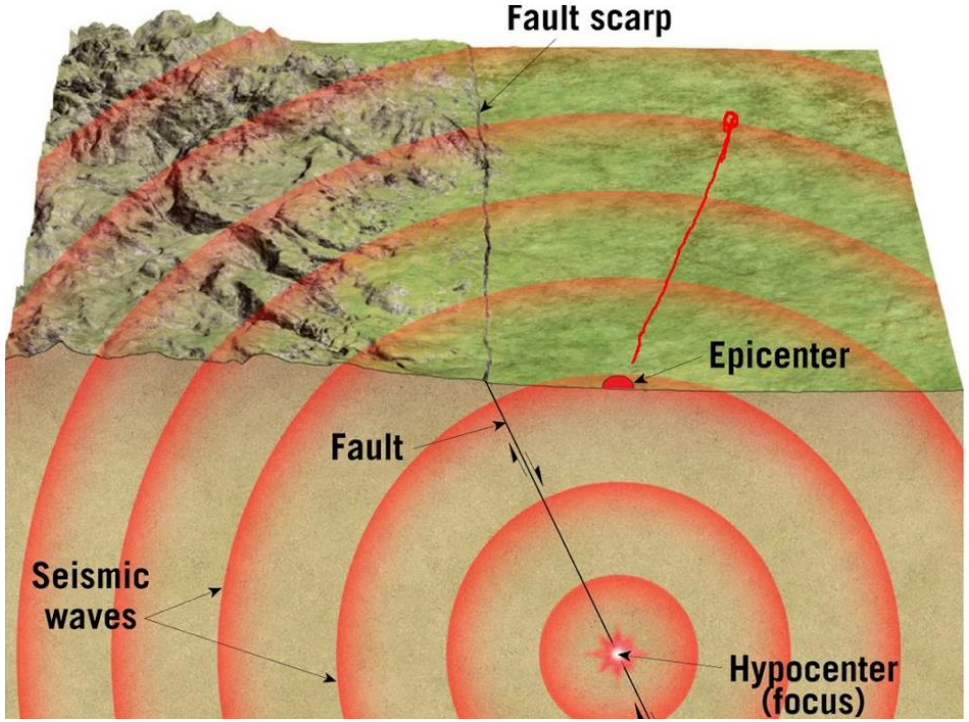


Magnitude (Quelle: IRIS, Washington) Link zu:
http://www.iris.washington.edu/seismic/events/

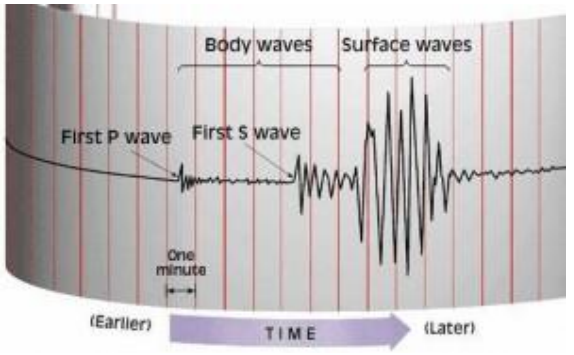
Each step ca. 30-fold energy release

But this does not apply to the earthquake loads.

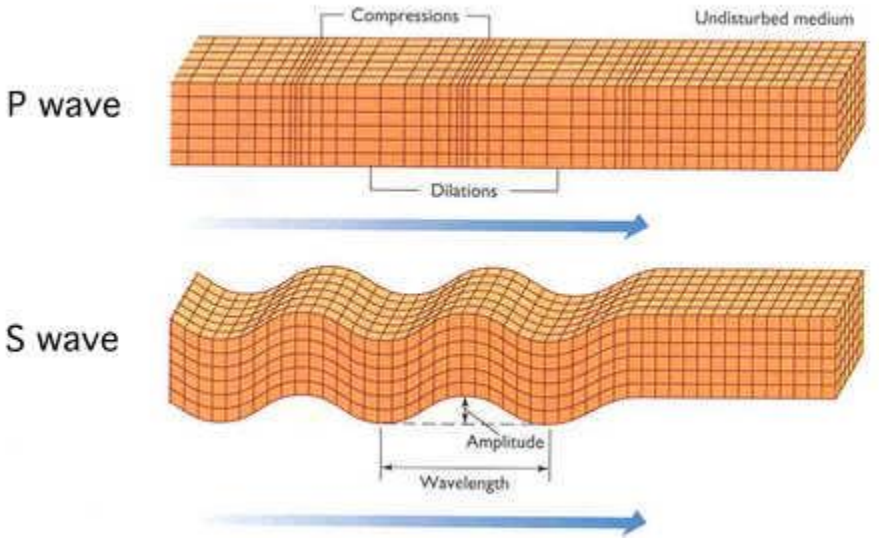
Vertical excitations dominate at the epicenter.



Earthquakes generate space waves (3d).
>> horizontal as well as vertical excitations!



acceleration-time-diagram
wikipedia



https://temblor.net/earthquake-insights/kaikoura-new-zealand-earthquake-yields-stunning-imagery-and-questions-1940/

The largest movements (up to several meters) occur along tectonic boundaries.
Therefore, avoid to settle there.

Interim result

- ✓ Earthquake shaking propagates spatially starting from the hypocenter. At the earth's surface and thus at the foundations, there are both **horizontal and vertical** components of the shaking (accelerations) in the Cartesian coordinate system. At the epicenter vertical shaking components might dominate.
- ✓ **Earthquake magnitudes** indicate the released energy of an earthquake. Energies (scalars) cannot be used to design buildings.
- ✓ **Earthquake intensities** indicate the subjectively assessed damage of earthquakes. If buildings are not earthquake-resistant, then a weak earthquake can result in a high intensity (large damage). The same earthquake produces a low intensity in a region with earthquake-resistant buildings (low damage).
- ✓ **Both, magnitudes as well as intensities are not relevant to earthquake engineers.**

Physical Parameters of Structural Motion

Are Magnitudes or Intensities helpful for the earthquake engineer? – No! – Why?

There is no physical relation between intensities / magnitudes and earthquake loads!

Differential equation of motion (Newton‘s law):

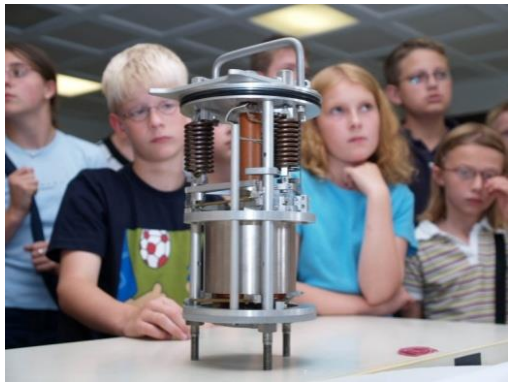
$$M \cdot \ddot{x}(t) + D \cdot \dot{x}(t) + K \cdot x(t) = f(t)$$

Isaac Newton (1642-1727)
Quelle: Wikimedia

For the design of structures **engineers need**:

- acceleration $\ddot{x}(t)$
- velocity $\dot{x}(t)$
- deformation $x(t)$

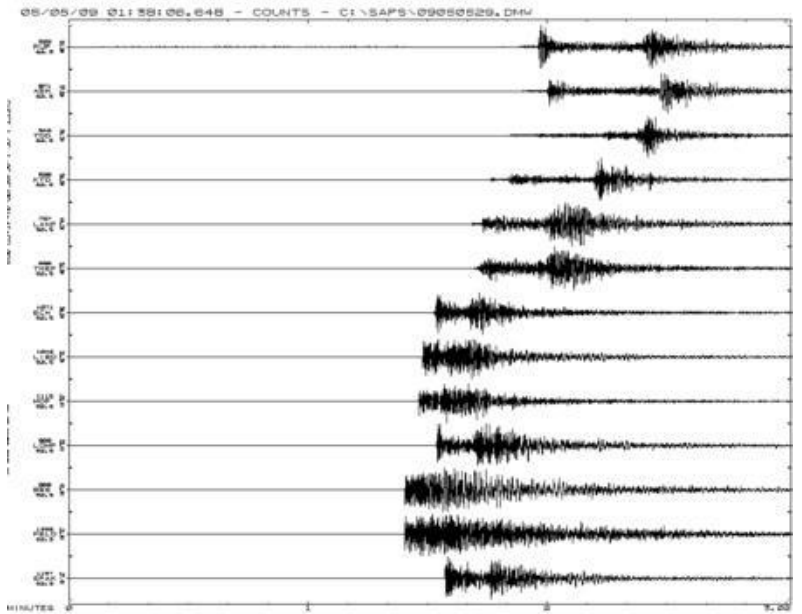
These motion variables (vectors) are recorded by seismographs.



Governing parameters:

- mass
- springs

DIN 4149, 5.4.1 (4):The **vertical component** of the earthquake action is ... the design value of acceleration ag according to Table 2 multiplied by a factor of 0.7.



$f(t)$

Which standards apply when - legally, physically?

According to DIN (https://www.din.de/de/ueber-normen-und-standards/normen-und-recht/rechtsverbindlichkeit-durch-normen):

- Standards are **not binding**, which distinguishes them from laws.
- DIN standards serve as an aid to decision-making in the event of a dispute. Courts refer to standards in order to assess whether the **generally recognized rules of technology** have been observed.
- **But, in construction practice: "Standards are laws"** (exclusion of liability).
- **Structural analysis and structural dynamics** are fields of **applied physics**. This applies globally without restriction. This applies above all to the **calculation methods**. Due to the global networking of science and technology, **planning and design guidelines are now also harmonized worldwide**. Only the **determination of safety is regulated nationally**.
- **From the point of view of structural analysis, EC 8, or the US guidelines NEHRP, FEMA P-749, or the Swiss standards SIA, as well as others, can be applied worldwide in order to build earthquake-adapted structures.** The inaccuracies on the action side (earthquake) are so great that "calculating with places after the decimal point creates a false sense of security".

Note: all **"geo-related" standards** apply only locally (impacts: earthquake, snow, wind, etc., soil, geology, etc).

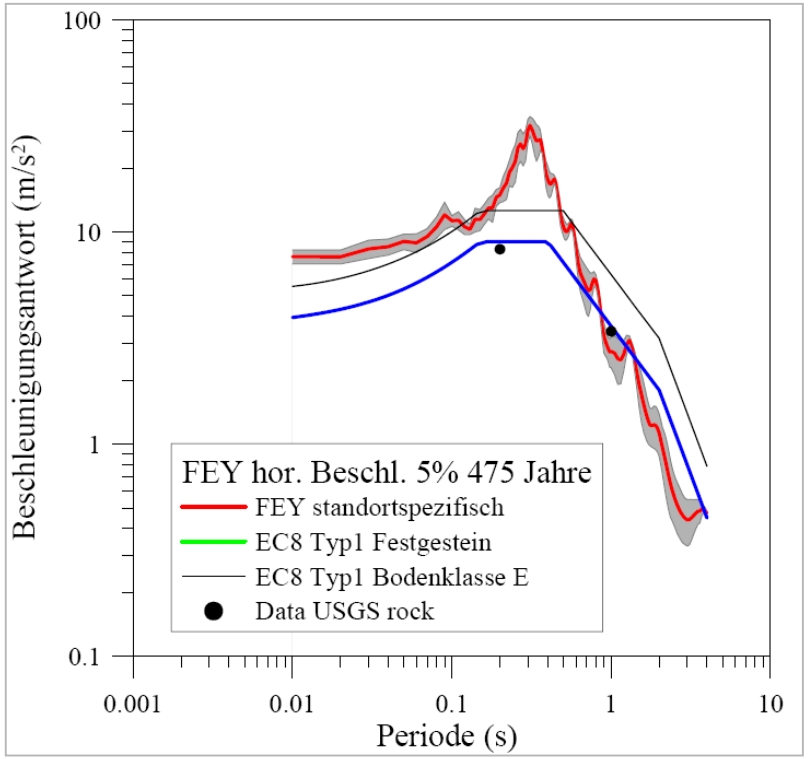
Response spectra
Design acceleration

Earthquake – design load

Earth quake in Mazar-i-sharif	VI Relating to account VII	زلزله در مزار شریف
The low temperature	-5.6 C°	درجه حرارت پائین
The highest temperature	50 C°	درجه حرارت بلند
The mid cold	-2 C°	درجه اوسط سردی
The mid hot	30 C°	درجه اوسط گرمی
Normal effect of the wind to the hight of 10m	30kg/m^2	تاثیر باد نورمال تا به ارتفاع 10m
Rain and sediments in year	223mm	بارزان و رسوبات در سال
sediments in autumn	50%	رسوبات در خزان
Sediments in winter	35%	رسوبات در زمستان
Sediments in spring	14%	رسوبات در بهار
The degree of pressure	730.6mm	درجه فشار به ستون سیماب
The conditional resistance of basement	15T/m^2	مقاومت شرطی تهداب
Interior water	13m	آب های زیر زمینی
Effect of freeze in to the deep	0.5m	تاثیر یخبندان تا به عمق
High from sea	387m	ارتفاع از سطح بحر

"Charge Sheet" of Afghan "Authorities“ (2007): Almost nothing was specified.

If there are no standards for action on buildings, then you have to search on international databases or create the database yourself.

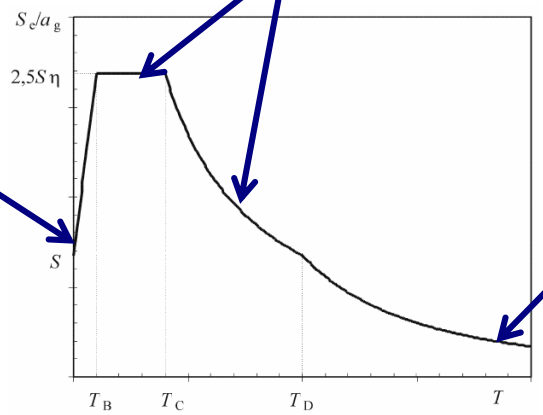


The red response spectrum can directly be used by engineers according to Newton‘s law.

Site specific response spectra are necessary!
(Prof. Dr. Hinzen)

Structural design: Fundamental decision

Rigid or **Flexible** or **Soft**



Stiffness and period
might change due to damage!

Elastic response spectrum

Depends on use of building!

- As an **architect** or **consulting engineer**, they must also carefully check the information in the tenders, especially when building abroad. **All geo-related standards (impacts, loads, soil, etc.) apply only to a specific region.**

- **Building owners** have a **special responsibility** when building in seismic areas, for example, in determining design and calculation parameters, such as the significance coefficients, with which loads (PGA) are to be multiplied.

Tabelle 3 — Bedeutungskategorien und Bedeutungsbeiwerte für Hochbauten

Bedeutungskategorie	Bauwerke	Bedeutungsbeiwert γ_I
I	Bauwerke von geringer Bedeutung für die öffentliche Sicherheit, z. B. landwirtschaftliche Bauten usw.	0,8
II	Gewöhnliche Bauten, die nicht zu den anderen Kategorien gehören, z. B. Wohngebäude	1,0
III	Bauwerke, deren Widerstandsfähigkeit gegen Erdbeben im Hinblick auf die mit einem Einsturz verbundenen Folgen wichtig ist, z. B. große Wohnanlagen, Verwaltungsgebäude, Schulen, Versammlungshallen, kulturelle Einrichtungen, Kaufhäuser usw.	1,2
IV	Bauwerke, deren Unversehrtheit im Erdbebenfall von Bedeutung für den Schutz der Allgemeinheit ist, z. B. Krankenhäuser, wichtige Einrichtungen des Katastrophenschutzes und der Sicherheitskräfte, Feuerwehrhäuser usw.	1,4

- From PGA > 5 m/s^2, it is often more economical to install base isolation than to design the structure completely for earthquakes.

Earthquake – Remarks (ctd.)

- What about the responsibility or liability of those who tender "incorrectly" and award to contractors who do not have relevant experience? Usually we have a price competition.

Design

Architectural
Structural

Earthquake resistant design

- DIN 4149: area of vailidity: Buildings in **German earthquake region** (earthquakes of low intensity)
- DIN EN 1998-1 (EC 8): area of validity: CEN member states (DIN 4149 is NAD)

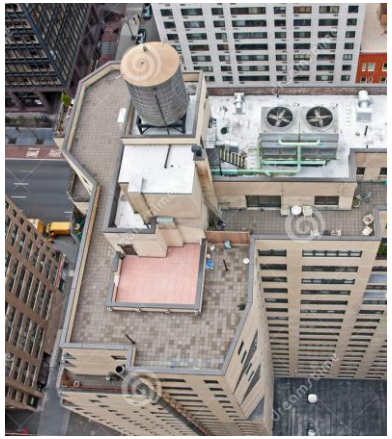
Fundamentals:

Buildings have to be designed **and** built such (ductility, redundancy), that they resist the design earthquake and that they have a sufficient residual carrying capacity after the earthquake.

Not load bearing elements have to be designed and attached such that they **do not endanger people.**

Photo: MJG

Improper fixation of roof girder, Indonesia GI



Water basin on roof top
Wikipedia Royalty-Free Stock Photo

Statue, Stanford, 1906 (Wikipedia)

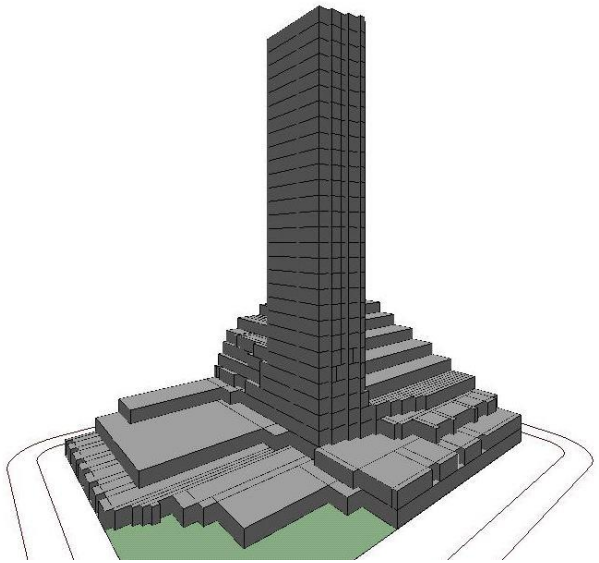
Earthquake resistant design

Design principles:

- simplicity
- equal stiffness in principal directions
- no jumps in stiffness
- high torsional stiffness (no open sections)
- no mass eccentricities
- slabs are rigid
- foundation is rigid
- ductility and energy dissipation
- no heavy masses on top

Regularity in **ground plan**:

- simplicity
- equal stiffness in principal directions
- no jumps in stiffness
- high torsional stiffness (no open sections)
- no mass eccentricities
- masses evenly distributed
- slabs are rigid
- layout of ground plan compact, no H or X or L
- no return corners



Regularity in **elevation**:

- simplicity
- equal stiffness in principal directions
- no jumps in stiffness
- load bearing structural elements constant over height
- masses constantly distributed over height
- avoid jumps
- no heavy masses in upper floors

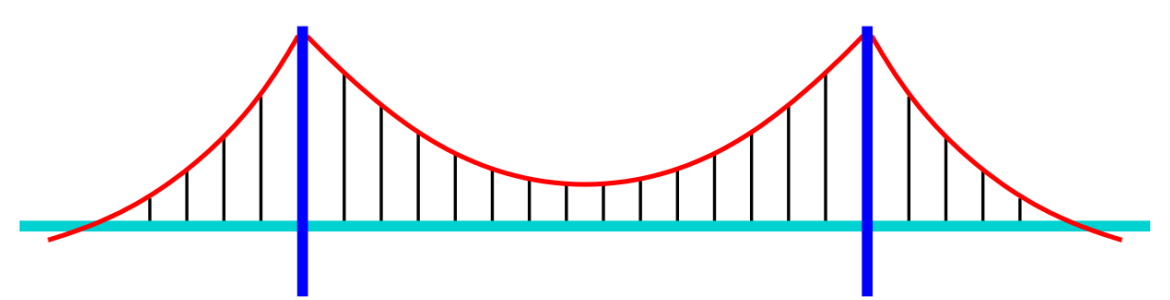
>> Make it simple, smooth and light

A hemisphere is the best solution for earthquake-resistant construction.

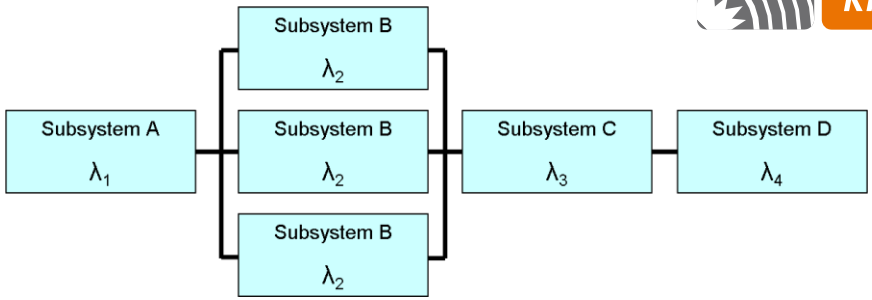
Aerial view of earthquake-resistant **dome houses** in Aso Farm Land, Kumamoto prefecture, Japan, made of styrofoam. Photo: Alamy. (Wikipedia)

Structural design – redundancy

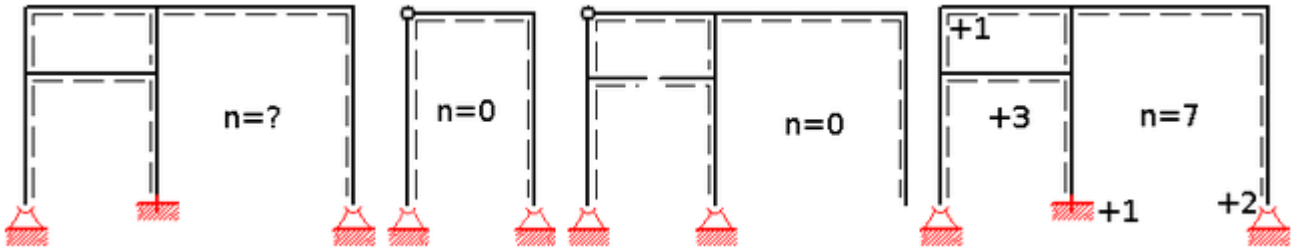
Structural **Redundancy** is required



A suspension bridge's numerous cables are a form of redundancy.



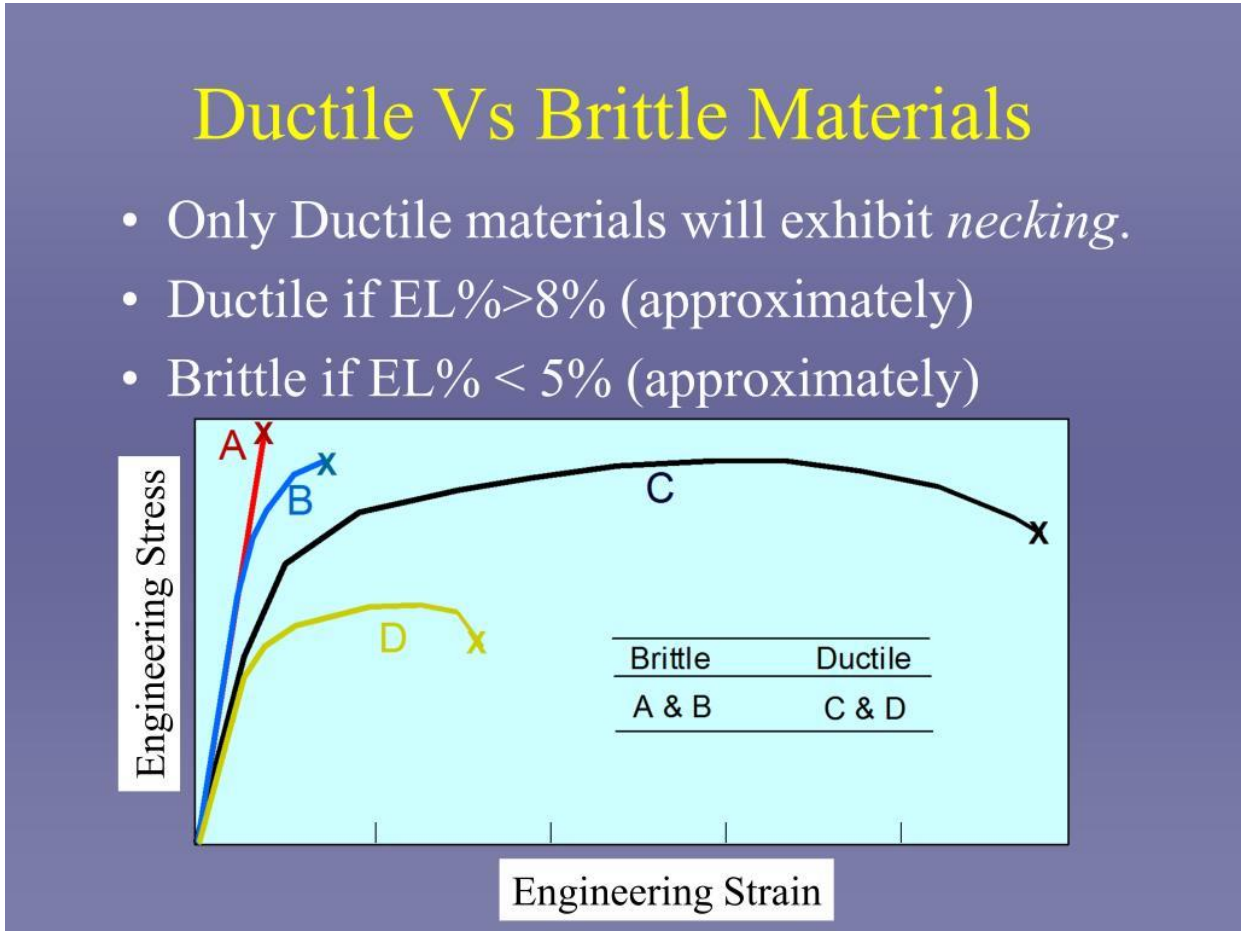
Triple modular redundancy (n=3)



The greater the static **indeterminacy**, the greater the structural **redundancy**. If one structural members fails, the remaining members may carry the remaining load (**alternative load path method**).

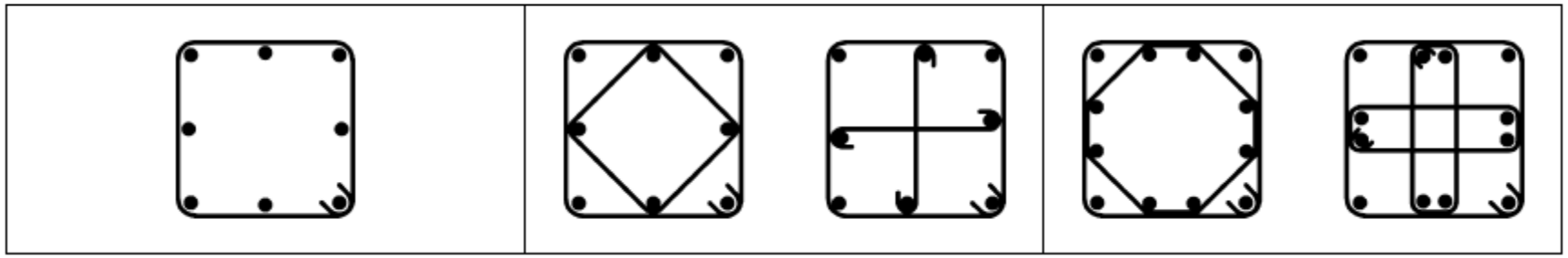
Structural detailing

Ductility is required



Concrete is brittle – Structural steel is ductile – steel reinforced concrete can be ductile, if and only if the reinforcement is properly designed

Structural detailing – reinforced concrete



Design of stirrups, **hooks bended 135°! Swivel stirrup locks** to avoid zipper-effect
Small reinforcing **bar diameters**, **small spacing** > **cage for crushed concrete** > **redundancy, ductility and residual carrying capacity!!!!**

Bewehrungsplan

EC 8 Teil 1 - Bild 5.6

Diagonal rebars prevent ripping of the corners when the building is shaking.

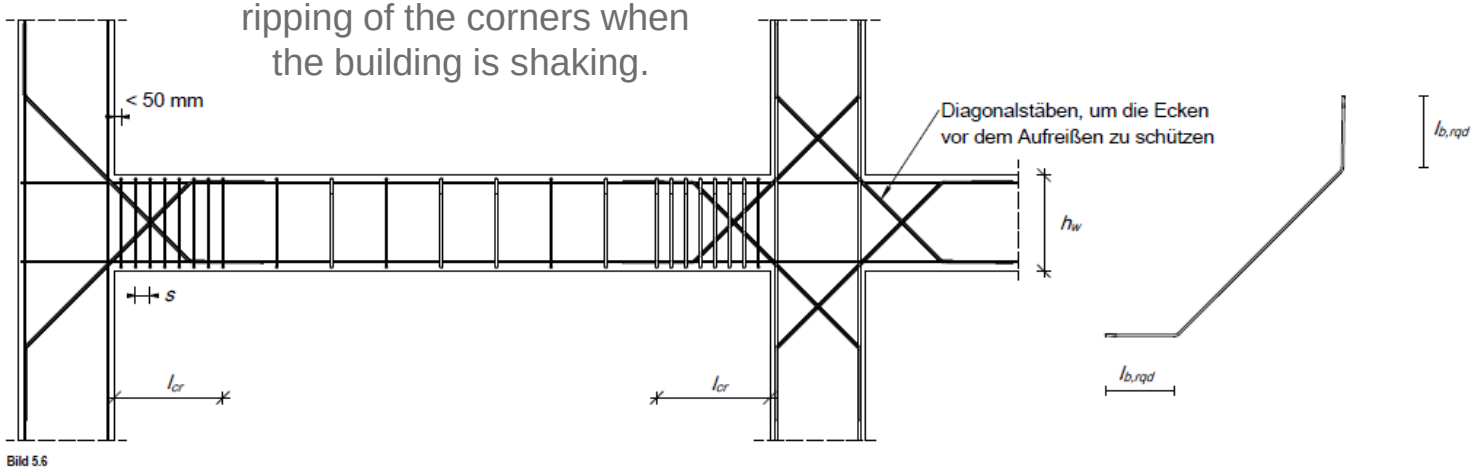
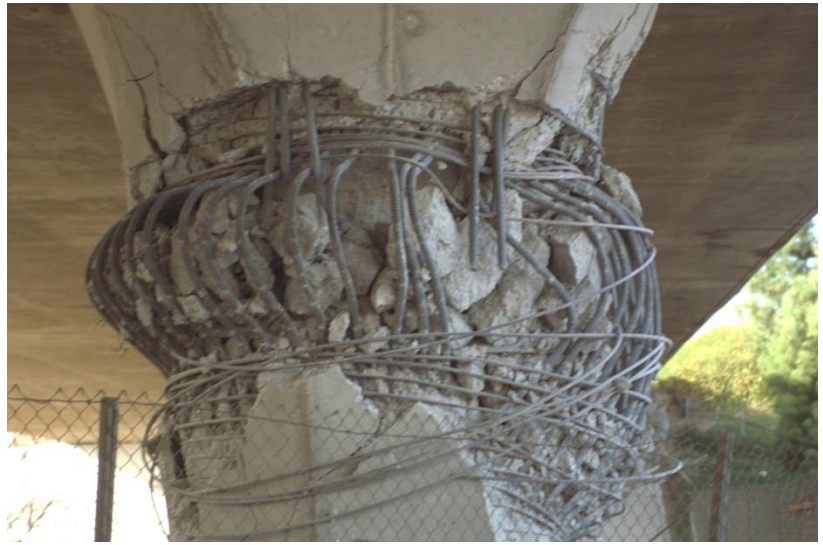


Bild 5.6

Earthquake resistant structural detailing is more expensive than structural detailing for static load cases.

Structural detailing – reinforced concrete



Collapse, elephant footing,
influence of horizontal and vertical acceleration

In all cases: reinforcement is not ductile!

Failure of primary- and secondary structure

Inspection on site

Codes + Guidelines – Assessment of Existing Buildings

- EC8 – 3 (DIN EN 1998-1) - Design of Structures for Earthquake Resistance, Assessment and Retrofitting of Buildings (1998) (not released in GER)
- BBR – Richtlinie Erdbebensicherheit (2012)
- BBR – Leitfaden zur Durchführung und Dokumentation der Zustandserfassung und Zustandsbeurteilung von Bestandsgebäuden im Liegenschaftsbereich des Auswärtigen Amtes im Ausland im Hinblick auf die Standsicherheit bei Erdbebenbeanspruchung (2006)
- ASCE/SEI 31-03 - Seismic Evaluation of Existing Buildings (1998)
- ASCE/SEI 41-15 - Seismic Rehabilitation of Existing Buildings (2007)
- FEMA 154 - Rapid Visual Screening of Buildings for Potential Seismic Hazards (2015)
- FEMA 356 - Prestandard and Commentary for the Seismic Rehabilitation of Buildings (2000)
- FEMA 547 - Techniques for the Seismic Rehabilitation of Existing Buildings (2006)
- FEMA 310 - Handbook for the Seismic Evaluation of Existing Buildings (1998)
- SIA 462 – Beurteilung der Tragsicherheit bestehender Bauwerke (1994)
- SIA 2018 – Beurteilung der Erdbebensicherheit bestehender Gebäude (2005)

- DIN 4149 – Bauten in deutschen Erdbebengebieten – Lastannahmen, Bemessung und Ausführung üblicher Hochbauten (2005) – regelt nicht Erkundung Bestandsbauten
- SIA 261 - Einwirkungen – Erdbeben
- UFC 3-310-03A – Seismic Design for Buildings (2005)

In order to meet the real project situation, the inspection takes place on several levels, ranging from simple visual inspection to very precise investigation.

Process:

1. Visual inspection (exterior, interior)
2. Inspection within hand reach
3. Non destructive inspection and testing
4. Destructive inspection
5. Material testing

Gebbeken, Braun, Hachmann, Yilmaz:
Earthquake Engineering – Reconnaissance and Assessment of Existing Buildings .Int. Journal of Protective Structures, 2012

Earthquake – Inspection devices (Toolbox)

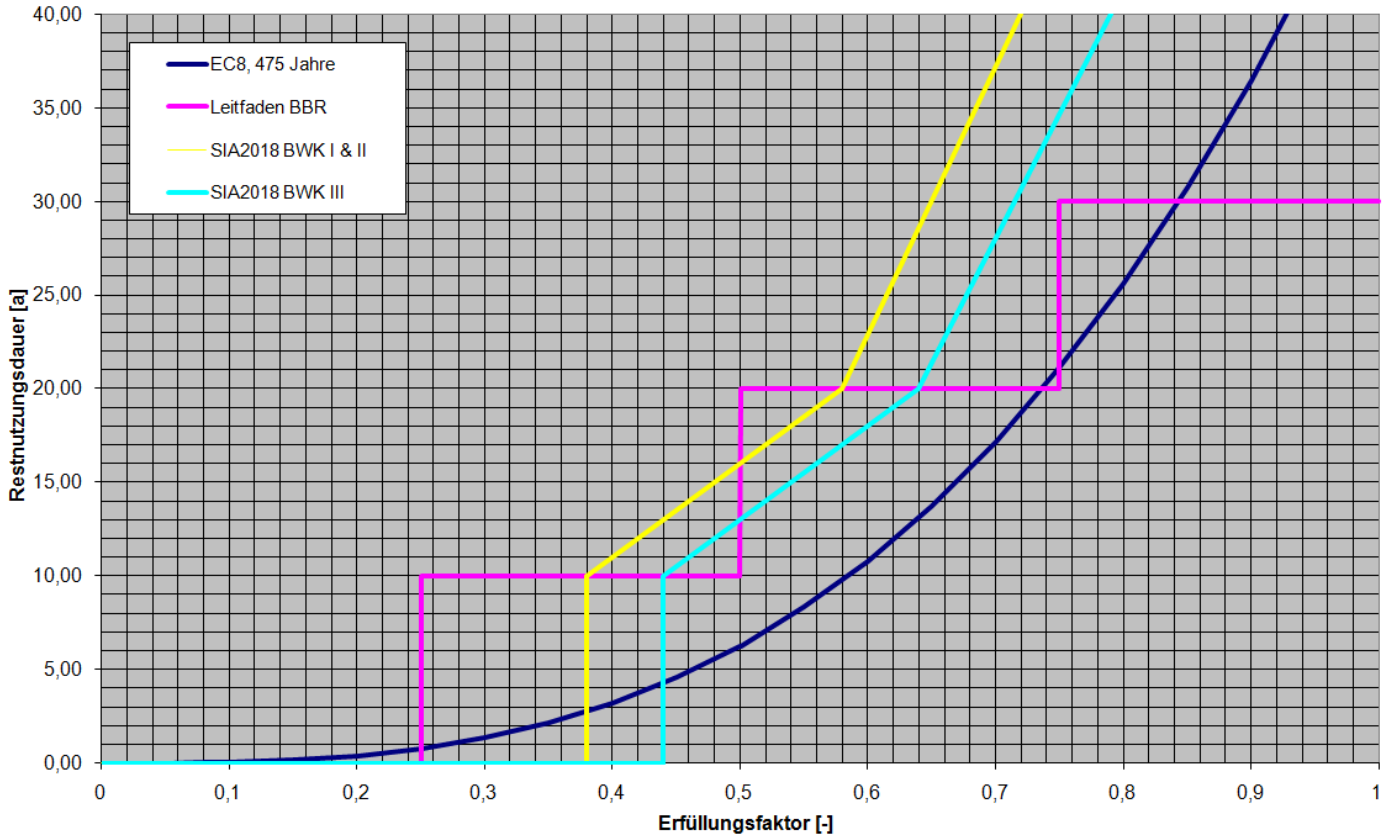
Tool	Picture	Purpose
Digital laser distance measurement equipment (Leica DISTO A5 and others)		Geometry measurement
Thermal imaging Camera (TESTO 875)		Identify structural elements behind wall-blinds and coverings. Identify wall characteristics and moisture.
Ferro scanner (Hilti PS 35 and others)		Find rebar Determine rebar depth

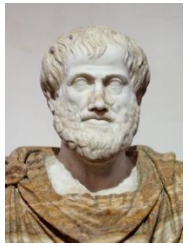
Tool	Picture	Purpose
Ferro Scanner (Hilti PS 200)		Quick mode: • Find rebar • Determine rebar depth • Record rebar distance Image scan mode: • Full rebar identification
Schmidt Hammer		Concrete strength determination
Endoscope Camera		Find objects behind panels and in cavities

Earthquake – Performance factor

Inspection and assessment
GER Federal properties abroad
> Determination of performance factor

Is security arbitrary?
Security is determined by the nation state, even in Europe.



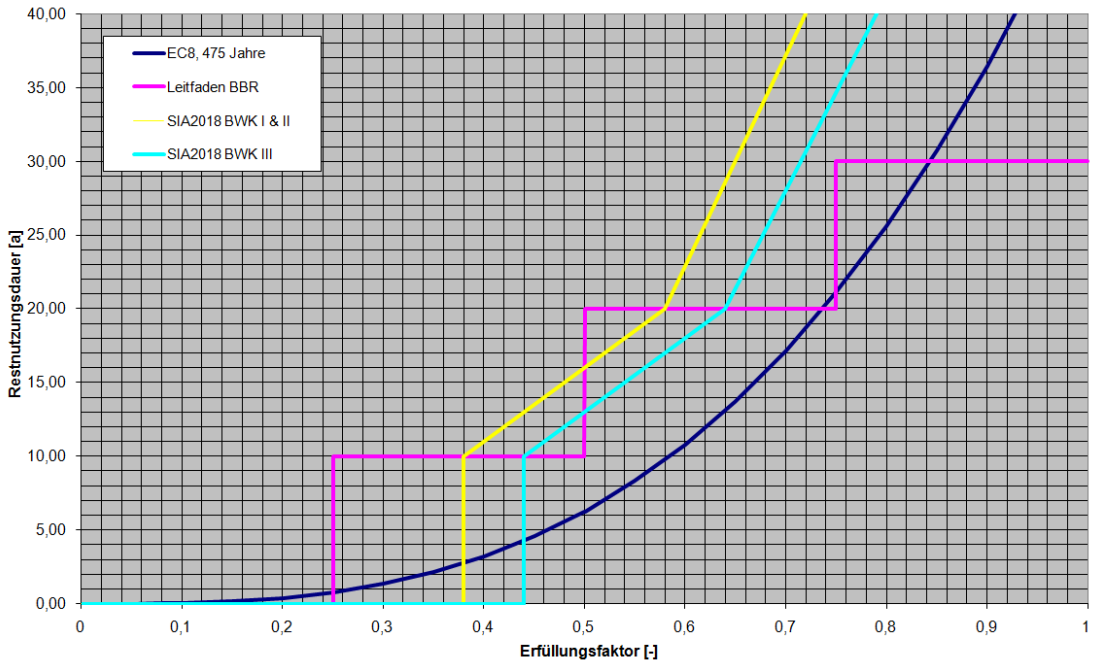


Aristoteles (384-322 v.Chr.): „Natura non facit saltus“ - Codes <> Natural laws

Lawyers are happy with any regulation, engineers despair.

Acc. to „Leitfaden BBR“, appendix Z (BBR Guideline):

Fulfillment factor	Action to be done
$\alpha_{eff} < 0{,}25$	building immediately strengthen, level $\alpha_{eff} = 0{,}5$, or move out
$0{,}25 \leq \alpha_{eff} < 0{,}50$	building strengthen asap, level $\alpha_{eff} = 1{,}0$, or move out
$0{,}50 \leq \alpha_{eff} < 0{,}75$	risk is acceptable, if renovation is planned, level $\alpha_{eff} =$ 1,0 should be reached
$\alpha_{eff} > 0{,}75$	risk is acceptable, if general renovation is planned, level $\alpha_{eff} = 1{,}0$ should be reached



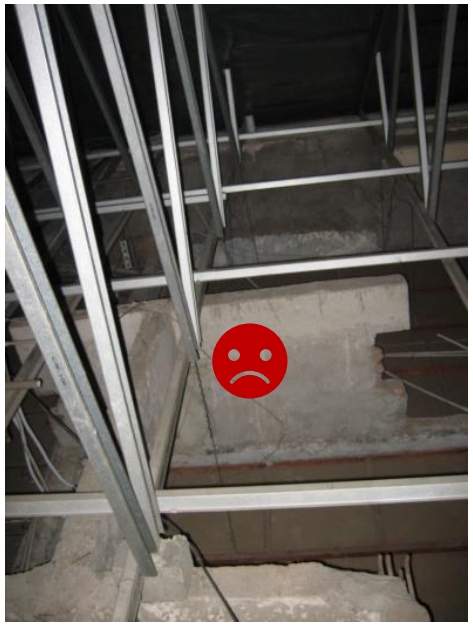
Assessment Computational Analysis Digital Twin

Earthquake - Inspection

Bandung, Indonesia

Inspection and assessment
GER Federal properties abroad
Earthquake safety
> Determination of performance factor

Roof tension anchor?



Masonry wall head not secured,
Ring anchor is missing

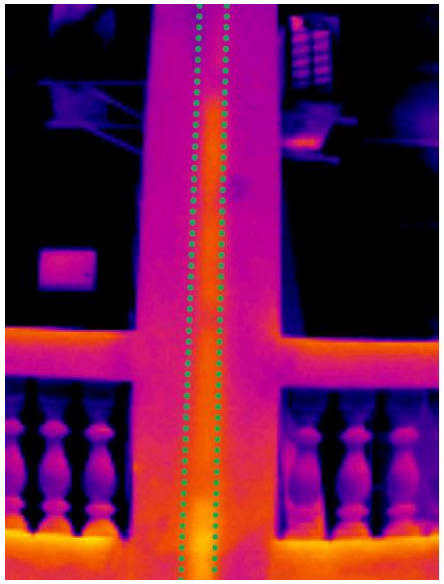
Djibouti Radio Station

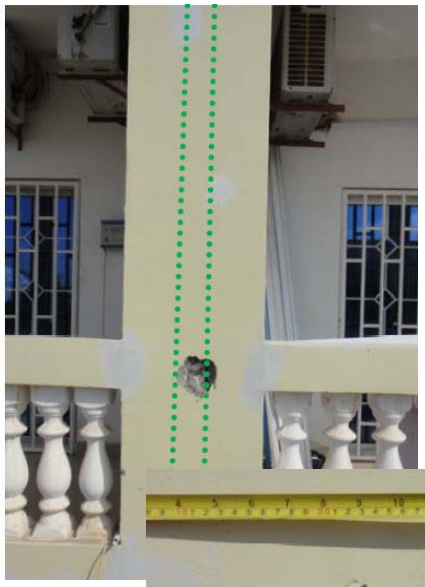
Photo

Digital twin

OPB
MJG

Earthquake – Inspection - Thermal Imaging

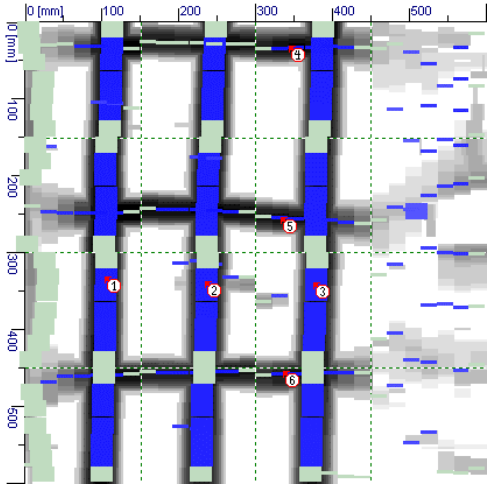


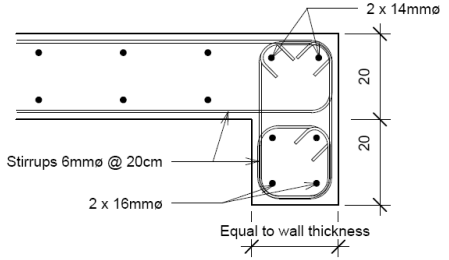


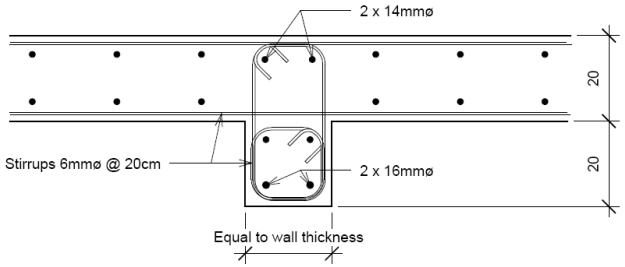
OPB
MJG

Thermal imaging detects a separation joint > semi detached house
> The two halfs of the buidling are structurally decoupled

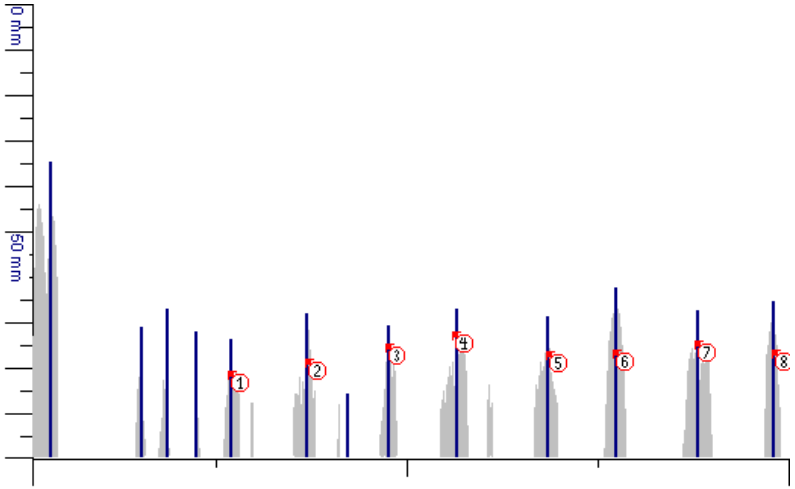
Earthquake – Inspection - Rebar scanning and verification







We discovered very good structural detailing!

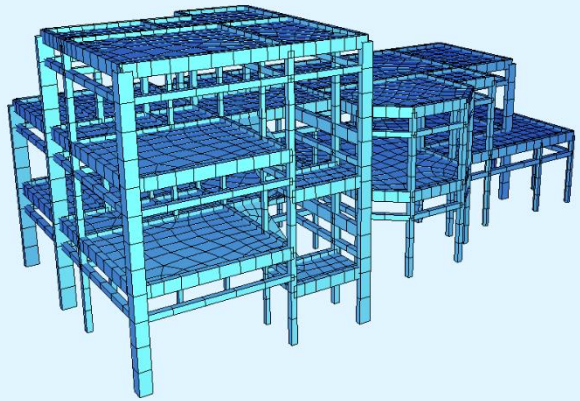


Rebar scanning

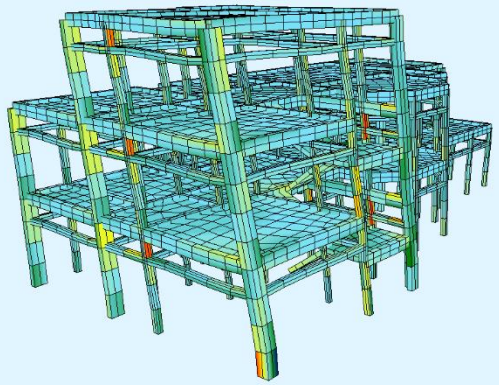
OPB
MJG

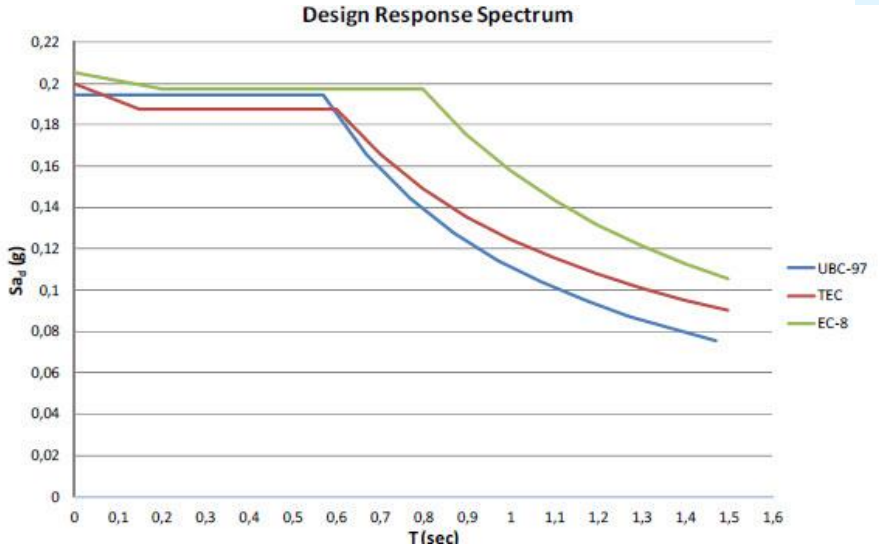
Concrete strength measuring (Schmidt hammer)

Earthquake – Numerical structural model



Images: MJG





Eigenmode analysis

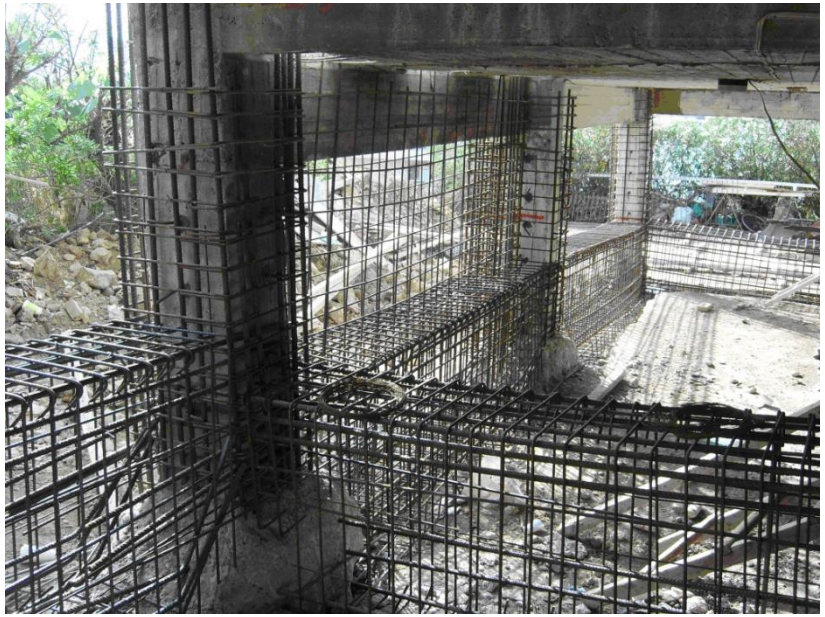
Application of three different codes for verification purposes (USA, Turkey, Europe).

Retrofitting (Hardening)

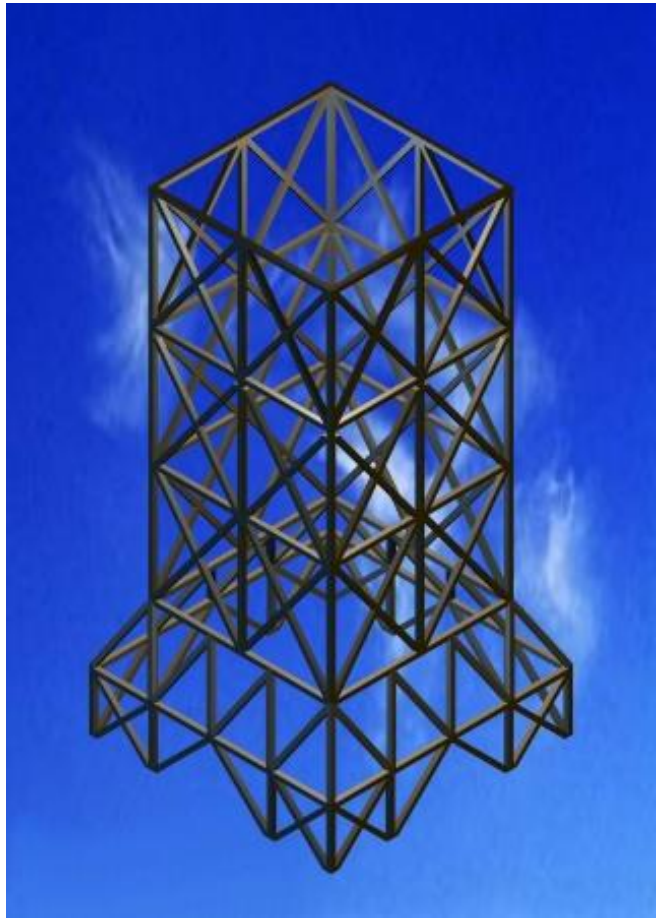
Structural detailing – strengthening of existing buildings

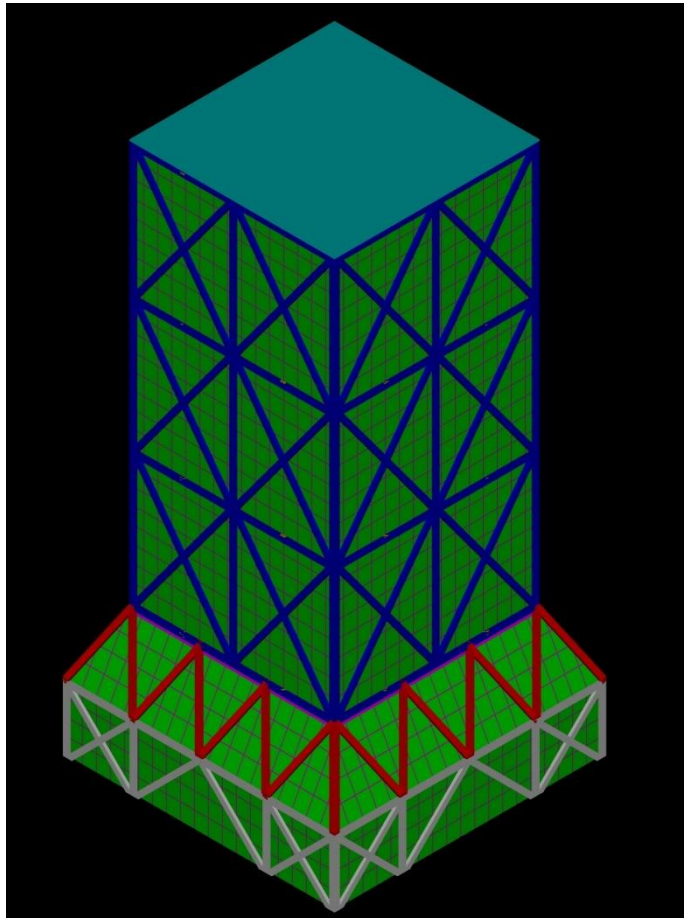
FRP - Jacketing

Ductile steel reinforcing



Support frame - jacketing





Our primary duty:

- Ensure **safety** in order to **avert danger to life and physical integrity** (GG Art.2 Abs 2, MBO, LBO, §249 StGB).
- How?

The advice of an engineer who has been in the business for almost 50 years.

- Install a four eyes checking mechanism (independent design review engineers)
- Design review engineers should be audited and supervised by the state and commissioned by the state (sovereign)
- Design review engineers must be independent consulting engineers that are independent from products and supply interests
- Design review engineers check the design, the construction drawings and supervise the execution
- Consulting engineers should be part of the liberal professions
- Design review engineers are personally liable

In the worst case, sloppiness and corruption cost lives!

Thank you! Questions? Recommendations?

Norbert Gebbeken

www.unibw.de/mechanik-und-statik/bauprotect

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