From “damage maps” to “condition inventories”: practically approved concept for inspecting modern & historic timber structures - not only bridges

☺

Frank Rinn, Heidelberg/Germany

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1. I am not a wood scientist and not an engineer but just a physicist!
2. After having worked as a carpenter on our family business, I studied physics and developed micro-resistance-drilling (1986-), methods for tree ring analysis (dendro-climatology), and sonic tomography for wood and concrete (at the end of the 1990ies), ...
3. Tree/timber inspection was a side-effect of scientific studies.
4. Since 1988 we inspected several hundred timber structures (including bridges), developed and evaluated application concepts in cooperation with authorities, engineers, architects, and carpenters.
5. This presentation: based on science but showing practical reality☺

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Introduction: timber inspection in Germany

- More than 2.5 Mill historic half-timbered buildings.
- More than 5 Million buildings with wooden ceiling beams
- More than 200 Billion Euro spend for buildings annually.
- 60% of the building budget is spent for restoration and repair.
- 1 - 3 Billion Euro annually for historical monuments.
- ca. 5% of new houses use structural timber (+10% p.a.).

> The need for timber inspection is growing, partially accelerated due to poor quality of design, wrong use of timber and lack of maintenance and knowledge (while money is getting shorter).

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Tasks and goals of timber structure inspection

- Maintain / repair timber structures cheap, fast, reliable:

  > simple but comprehensive concept of inspection

  > results presented clearly in short reports / inventory maps

- Preserve as much existing material / historic fabric as possible:

  > assessment as non-invasive and non-destructive as possible

  > assess even hidden beams under floor / behind stucco

  > determine stage and extension of decay as precise as possible

  > ...

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Major (legal) boundary conditions

- If a timber structure (building or bridge) does not show signs of overload and if the load will not increase in the future, only damaged parts have to be replaced in at least original size/quality.

  > assessment & evaluation of wood condition, only

  > looking + knocking + resistance drilling

- If overload signs are detected or load will increase, load carrying capacity has to be assessed in addition to condition. **This happens in less than 5% of the inspections on the market!**

  > Then stress wave timing is used in addition to resistance drilling (=> wood density) for estimating MOE (≈Density * v^2).

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Major steps and aspects of the inspection concept

1. Create an inventory map, covering all relevant timber parts & connections:
   > No overlaying beams in one map! Clear coordinate system! ...
2. Conventional inspection: looking and tapping, moisture measurements.
3. Identifying decay/damage types (fungi, insects, bacteria, ...)
4. Technical assessment (where/if required):
   - 4.1 Calibratable resistance drilling for determining wood density and
     - 4.1.1 depth of external decay and internal condition
     - 4.1.2 location and condition of hidden/covered beams.
   - 4.2 If required: stress-wave timing for
     - 4.2.1 estimating MOE (combined with density)
     - 4.2.2 determining length of hidden beams.
5. Documentation and reporting: map/draw condition and not only location of decay!
   - 5.1 All relevant results and recommendations shown in colored condition sketch.
   - 5.2 Use as few as possible sketches covering as many parts/beams as possible.

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Some major practical aspects of the inspection

1. No high-resolution & precise 3D map required! A simple functional sketch showing all major structural parts is usually sufficient for documentation and repair execution!
2. Only calibratable resistance drilling profiles allow correct evaluation of wood condition!
3. Clear color coding with as few colors as possible (b/w copy!)
4. Always immediately document results in the inventory map on the spot because afterwards in the office the knowledge about the details is often lost/forgotten and there is no chance to immediately check in case of doubt / remaining questions.
5. The final result should be ready and on paper before leaving!
6. Keep text description and recommendations as short as possible.

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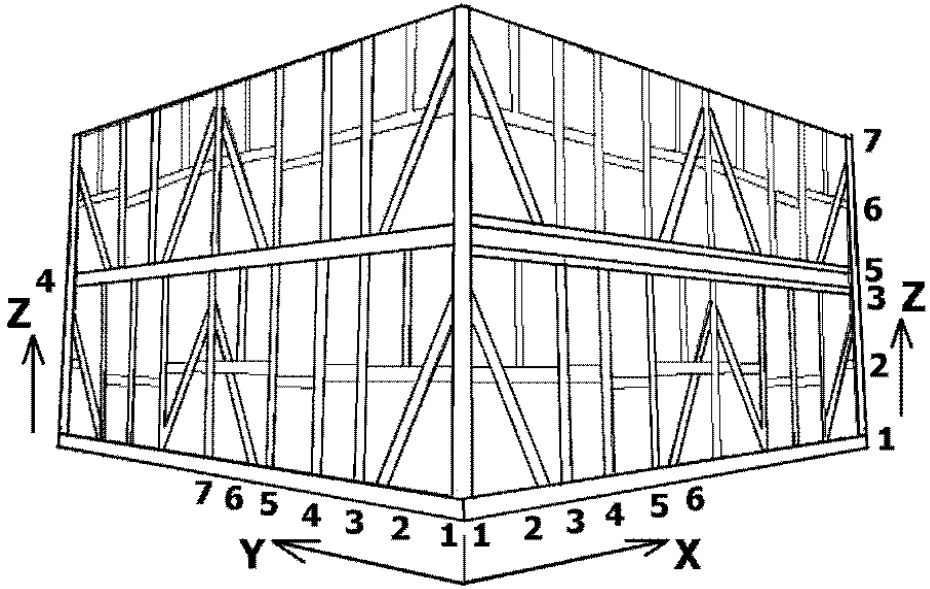
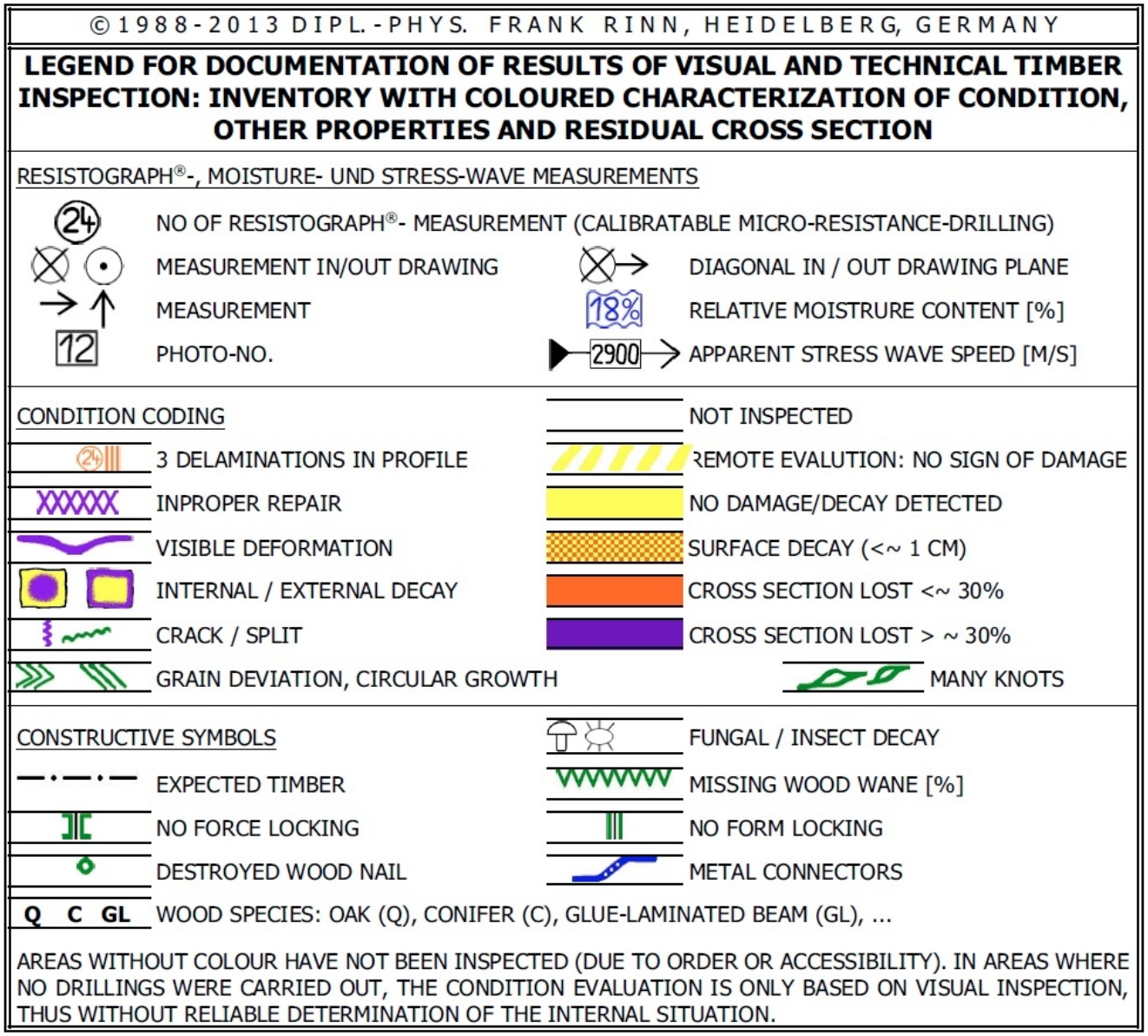


A simple coordinate system is pre-requisite for clearly marking beams, parts, and connections and labeling them with a position (x,y,z) that cannot be mixed up later.
Commonly, every structural axis is named with a number.



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LEGEND FOR DOCUMENTATION OF RESULTS OF VISUAL AND TECHNICAL TIMBER INSPECTION: INVENTORY WITH COLOURED CHARACTERIZATION OF CONDITION, OTHER PROPERTIES AND RESIDUAL CROSS SECTION

RESISTOGRAPH®-, MOISTURE- UND STRESS-WAVE MEASUREMENTS

- 24 — NO OF RESISTOGRAPH®- MEASUREMENT (CALIBRATABLE MICRO-RESISTANCE-DRILLING)
- MEASUREMENT IN/OUT DRAWING
- DIAGONAL IN / OUT DRAWING PLANE
- MEASUREMENT
- 18% — RELATIVE MOISTRURE CONTENT [%]
- 12 — PHOTO-NO.
- 2900 — APPARENT STRESS WAVE SPEED [M/S]

CONDITION CODING

- 3 DELAMINATIONS IN PROFILE
- INPROPER REPAIR
- VISIBLE DEFORMATION
- INTERNAL / EXTERNAL DECAY
- CRACK / SPLIT
- GRAIN DEVIATION, CIRCULAR GROWTH
- NOT INSPECTED
- REMOTE EVALUTION: NO SIGN OF DAMAGE
- NO DAMAGE/DECAY DETECTED
- SURFACE DECAY (<~ 1 CM)
- CROSS SECTION LOST <~ 30%
- CROSS SECTION LOST > ~ 30%
- MANY KNOTS

CONSTRUCTIVE SYMBOLS

- EXPECTED TIMBER
- NO FORCE LOCKING
- DESTROYED WOOD NAIL
- Q C GL — WOOD SPECIES: OAK (Q), CONIFER (C), GLUE-LAMINATED BEAM (GL), ...
- FUNGAL / INSECT DECAY
- MISSING WOOD WANE [%]
- NO FORM LOCKING
- METAL CONNECTORS

AREAS WITHOUT COLOUR HAVE NOT BEEN INSPECTED (DUE TO ORDER OR ACCESSIBILITY). IN AREAS WHERE NO DRILLINGS WERE CARRIED OUT, THE CONDITION EVALUATION IS ONLY BASED ON VISUAL INSPECTION, THUS WITHOUT RELIABLE DETERMINATION OF THE INTERNAL SITUATION.

Color coded inventory legend

=> not inspected parts have no color!

=> parts identified as intact are yellow!

=> special engineer symbols added

=> orientation of drillings included!

Two people are three times faster than one and thus much more efficient: one expert is taping, drilling, and measuring. The other one is documenting.

=> The final result (= colored inventory map) is made ready on the spot! (Later just scanned in the office)

- In several hundred of big and small inspections, in historic and modern structures, we carried out several hundred thousand micro drillings.
- In the average, the application of technical equipment (mainly resistance drilling and stress-wave techniques) covered ~30% of working time, but delivered ~70% of relevant results. In several projects, resistance drilling was more than 90% 'of the job' and cleared all the doubts. We drill until all questions are answered on site and final results are documented on paper.
- Biggest achievements and/or savings were mostly due to proper resistance drilling, often in hidden/invisible beams.
- All these achievements have been possible only by using calibratable resistance drills: only their profiles can be correlated clearly to a corresponding wood condition and thus interpreted correctly.
- Understanding market structure, architects, engineers, and carpenters as well as knowing wood anatomy and technical inspection is prerequisite for all this.

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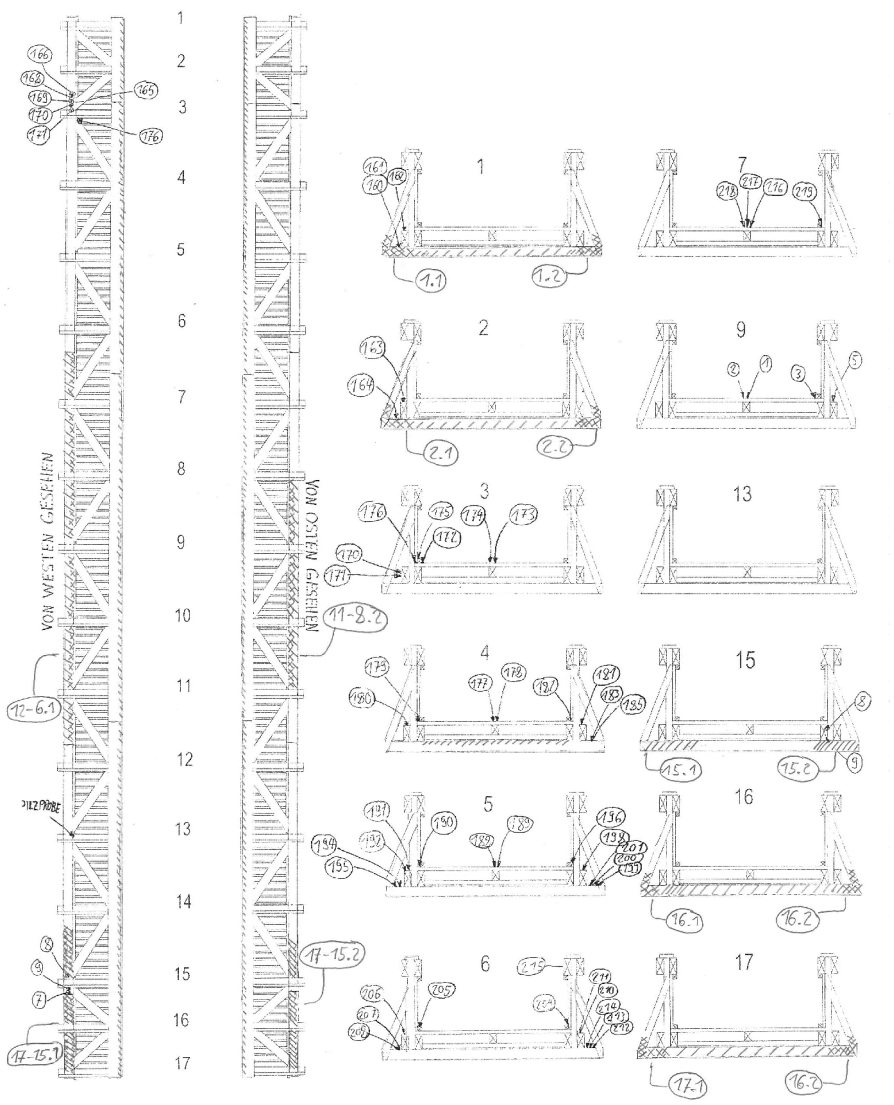
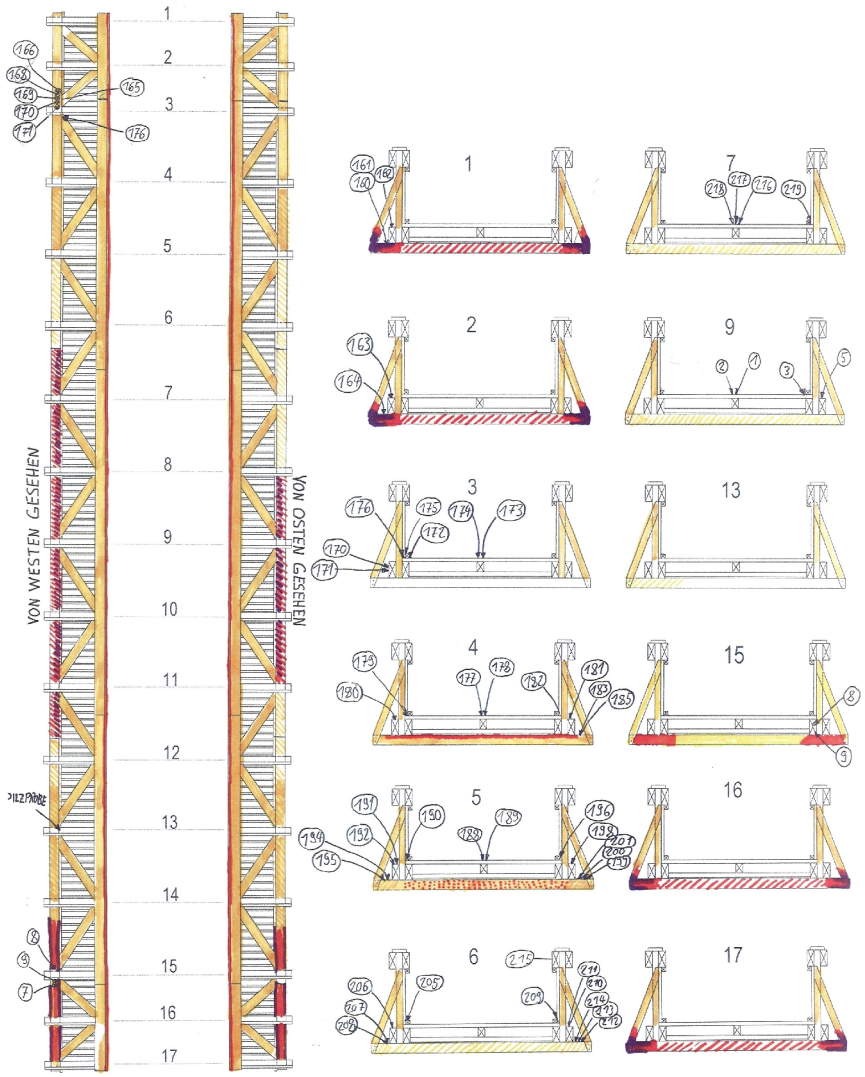


Typical black and white damage inventory as common for decades worldwide: damaged parts are marked by shading patterns.

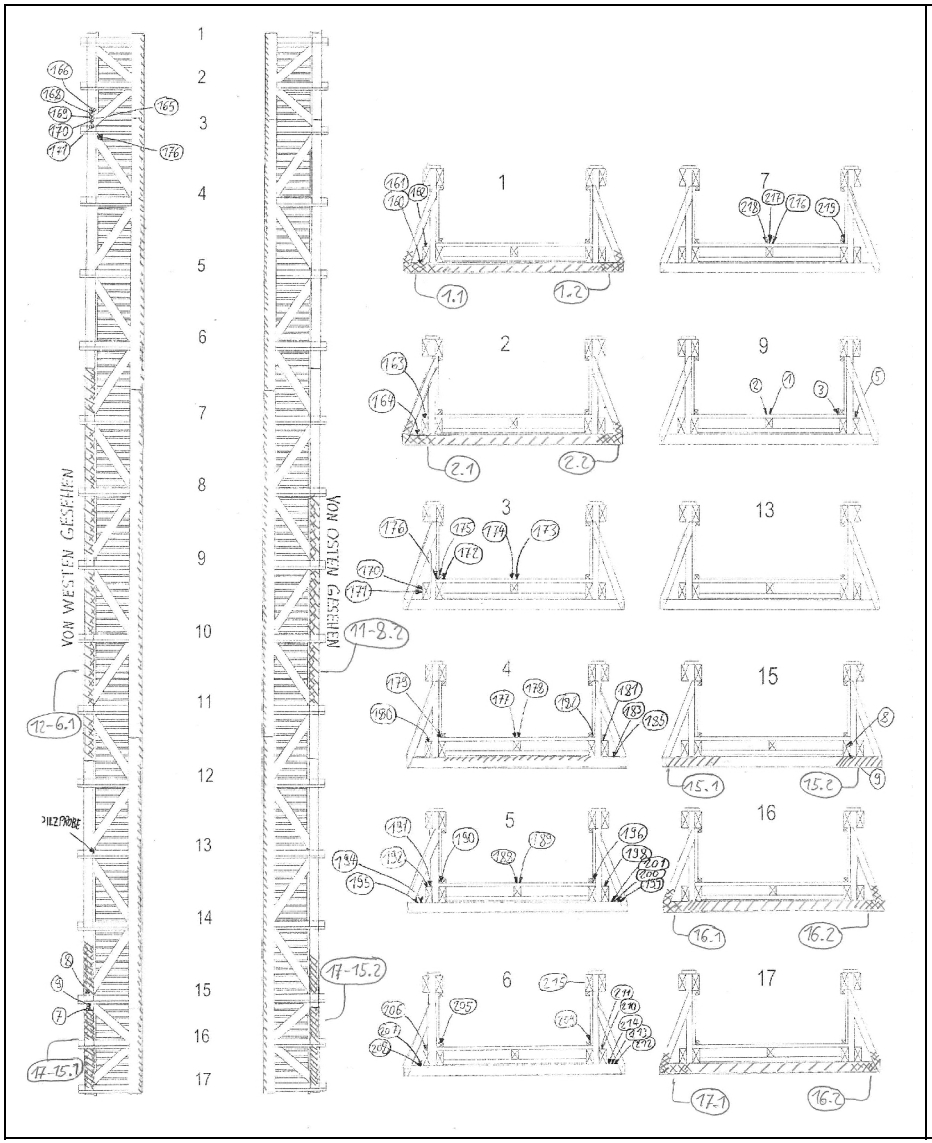
The engineer does not know if the other parts have not been inspected or if they are intact.

=> such uncertainties often lead to unnecessary work, just to be safe.



Color inventory map showing decay / deterioration in two different stages (orange -> red) and intact parts (yellow). Mostly, red or purple is used when more than 30% of the cross section is damaged (depending on kind of damage).

Beams that have not been inspected are white and without color, indicating there is no information on their condition.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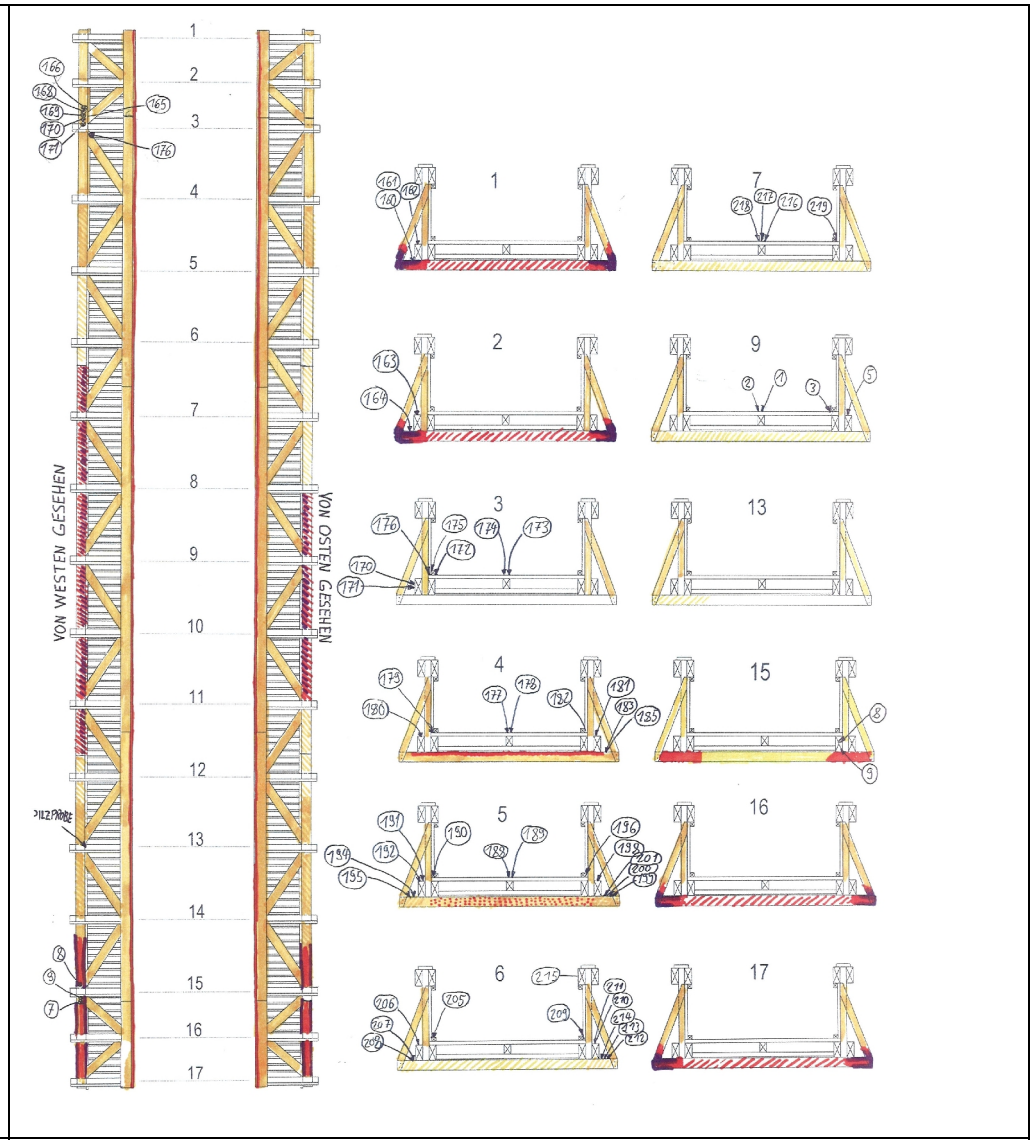
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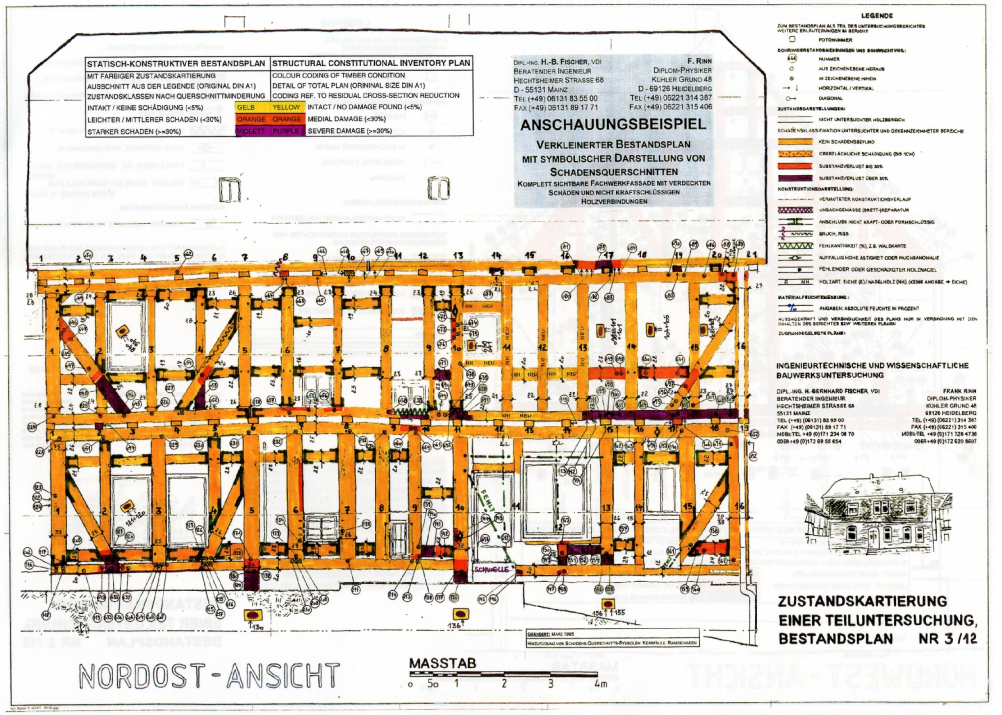
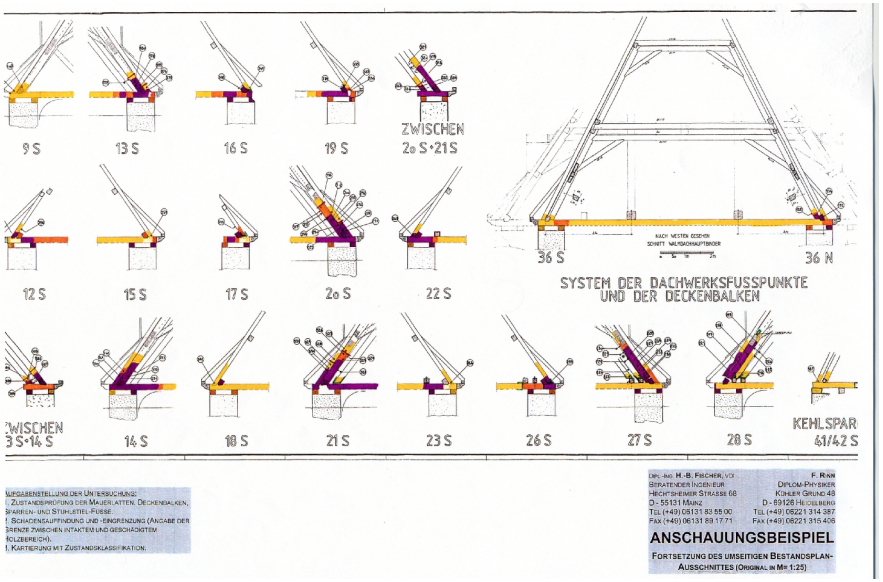
Locating 'hidden' beams and assessing their condition with resistance drilling without taking off the floor (or stucco).

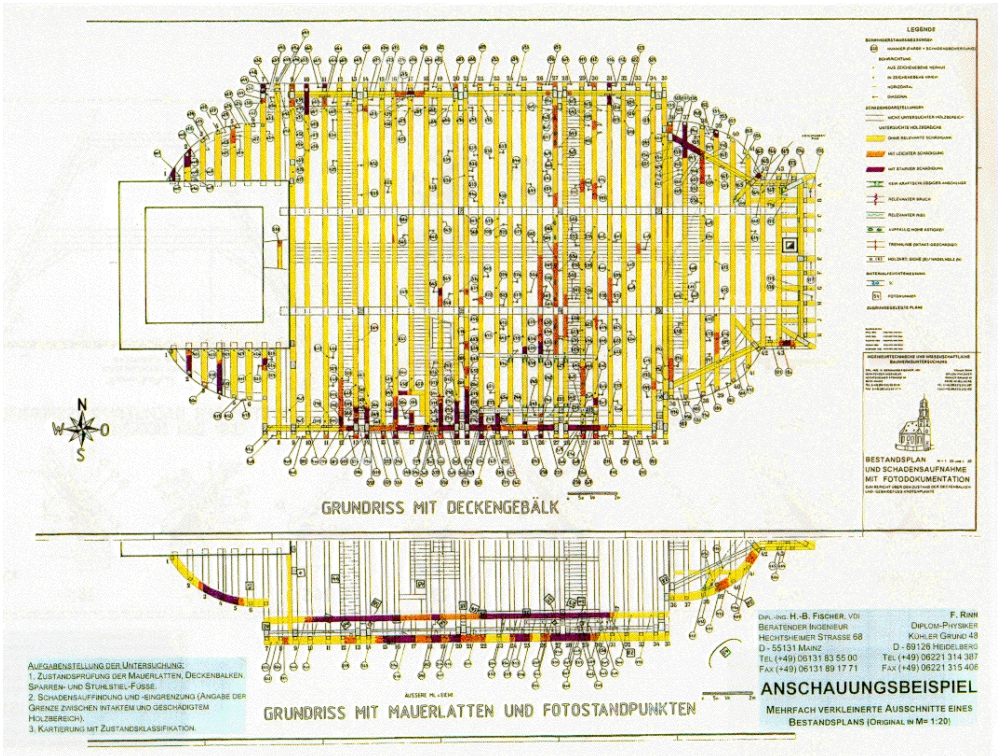
This often requires many drillings but they are fast meanwhile. Sometimes needles break while searching for beams => old needles are commonly used for that.

Fungal decay types are then determined with samples taken with / from endoscopes.

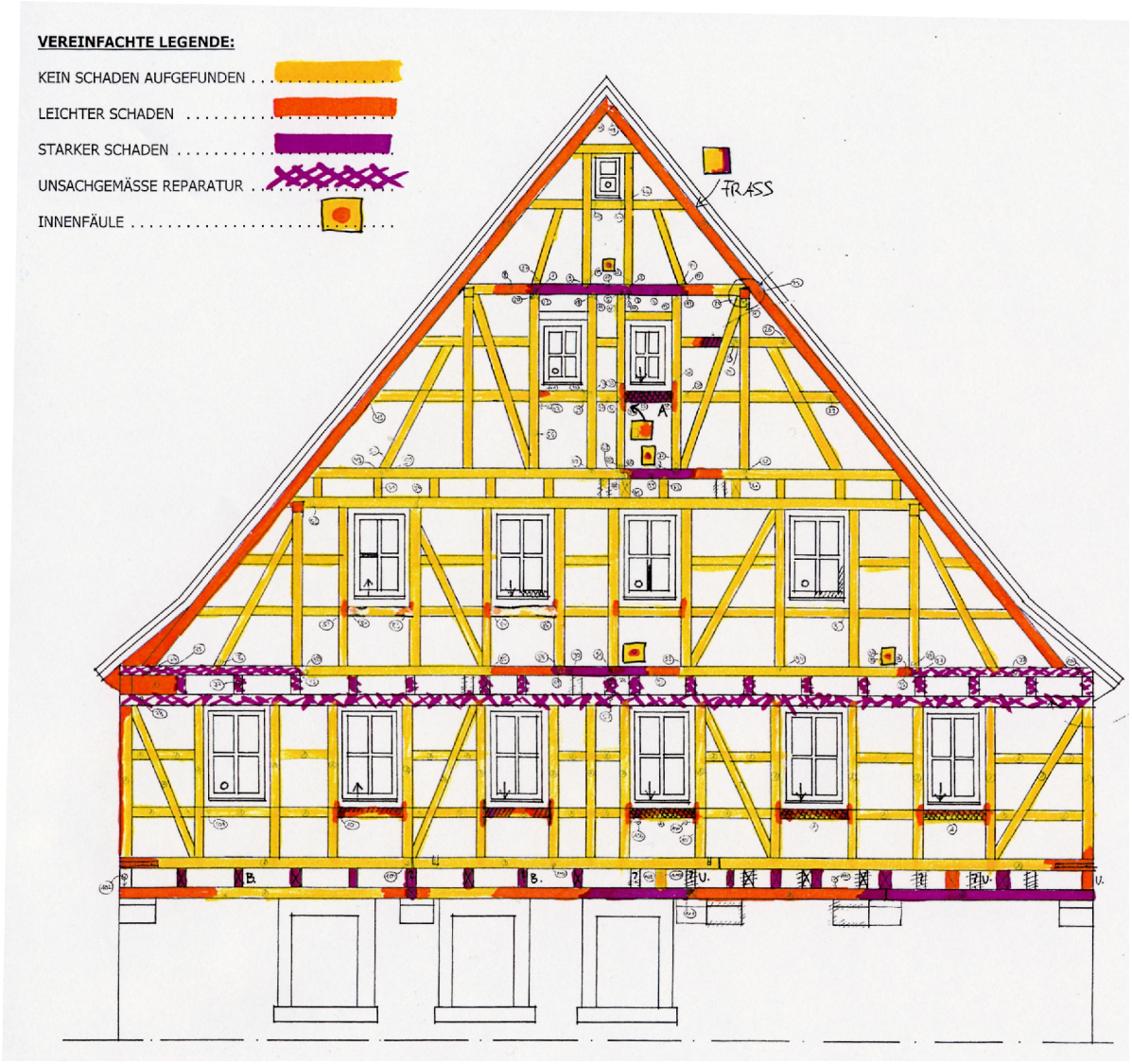


Historic building (1652): wall beams hidden behind wooden shindels and/or bricks => resistance drilling was used for locating beams and assessing their condition.





Church (~1780) with wood decay concentrated on (southern) wall: final repair costs = estimated costs +2%. Inspection: 600 resistance drillings, one week, two experts, achieved savings ca. 50% (~200'000€) compared to similar projects due to precise identification and location of decayed areas.



Simple map of a half timbered building.

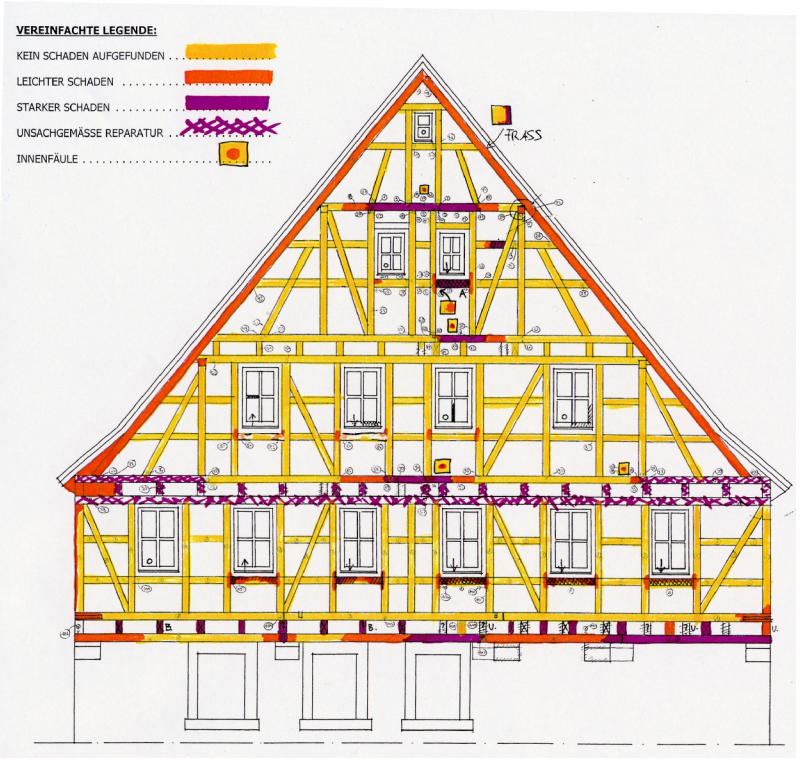
Inspection: one person one day.

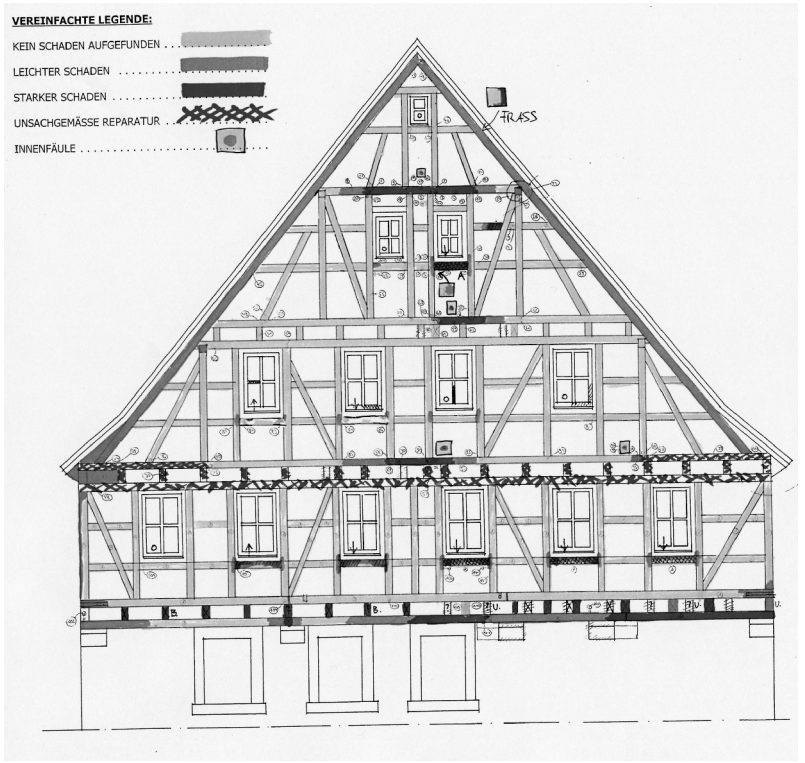
Costs: ~2'000 Euro

(incl. travel).

Savings ~50'000€.

Most decay was internal / hidden / invisible and would have led to unplanned additional work and time (and cost) in conventional restoration.





The colors used for coding the timber condition were selected in order to allow even black and white copies to work: the darker the worst the condition.

Areas with active fungal decay are usually marked red/purple.

Application examples from timber bridge inspections

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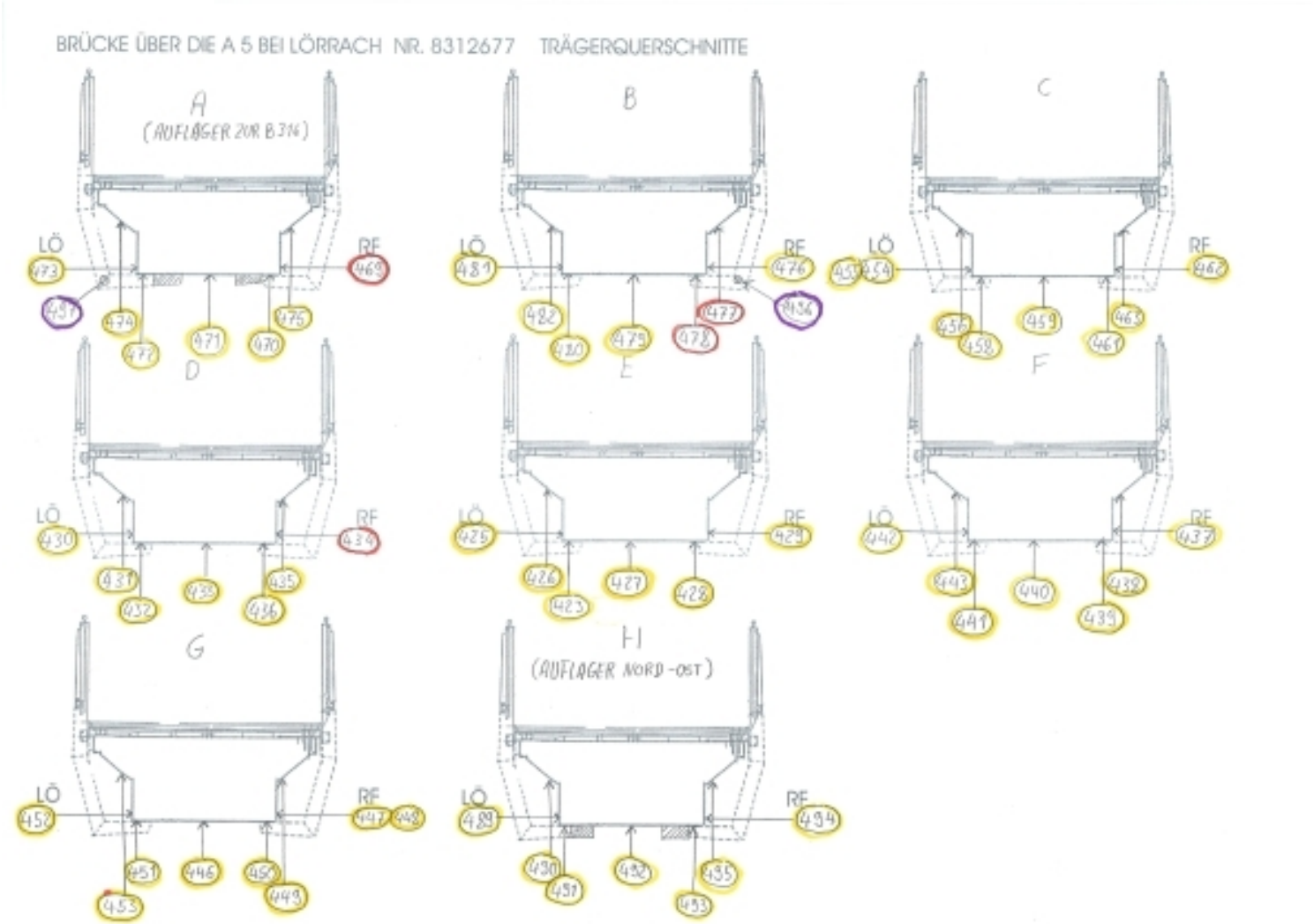
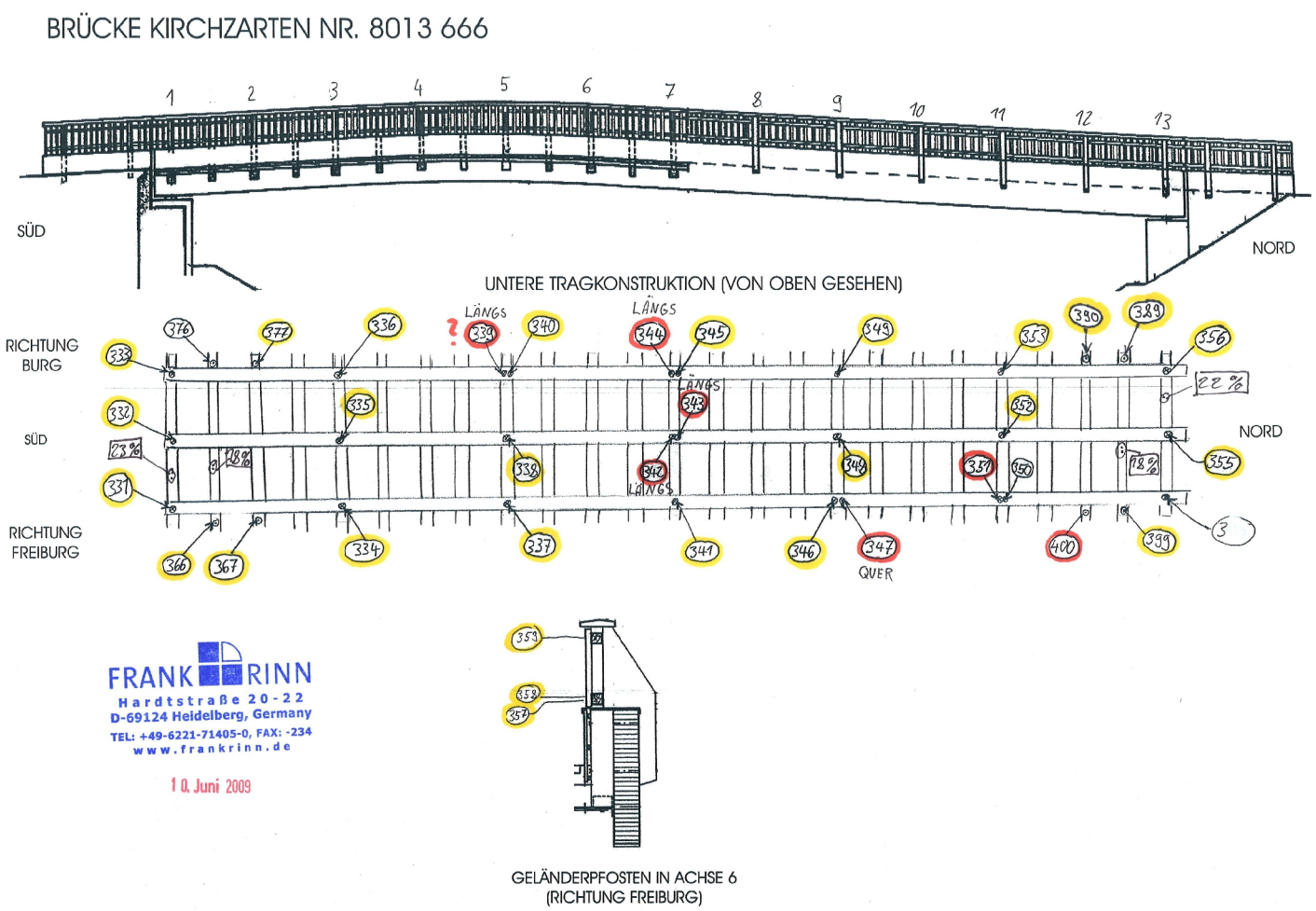


Application examples from timber bridge inspections



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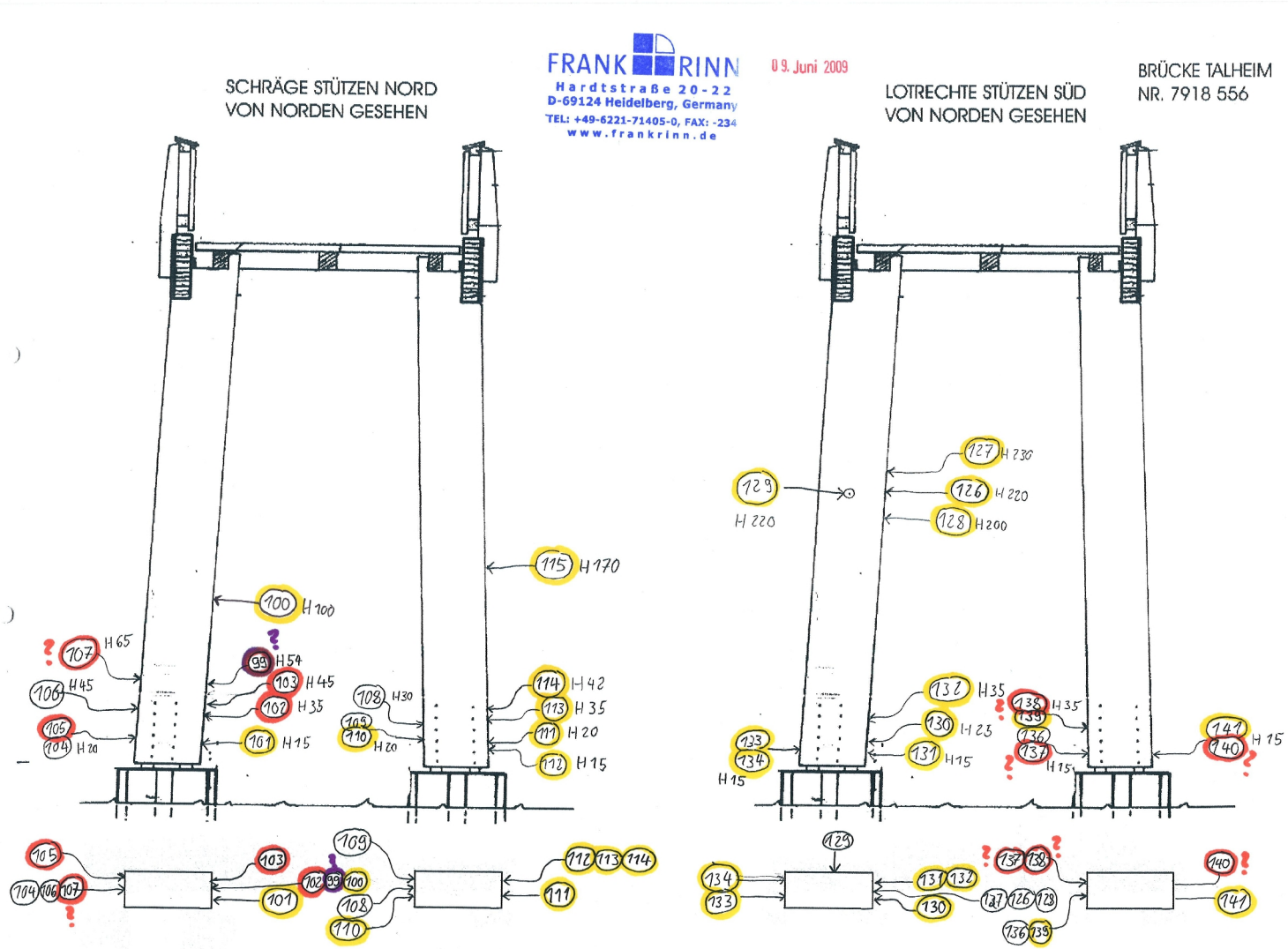
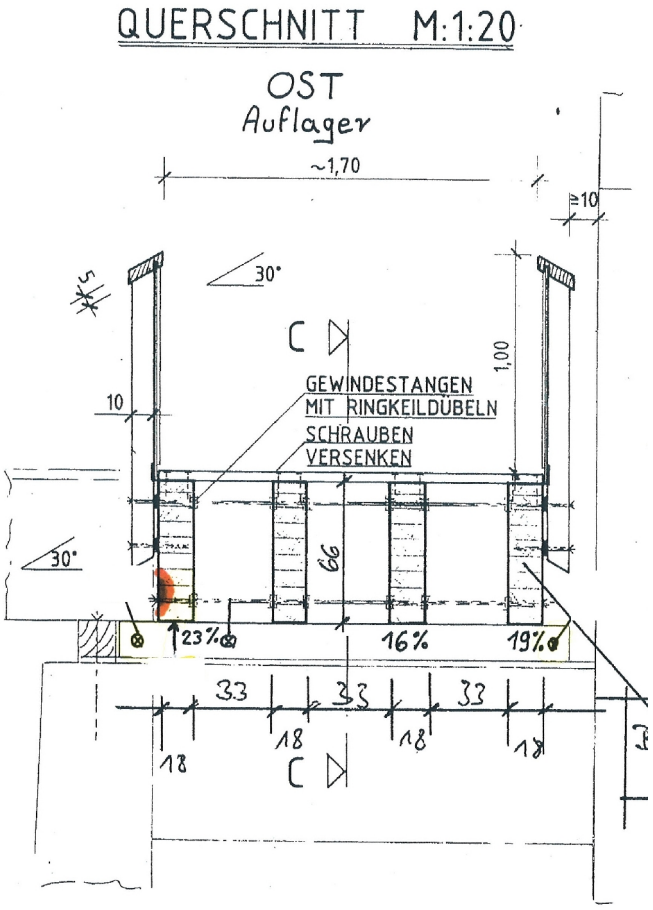
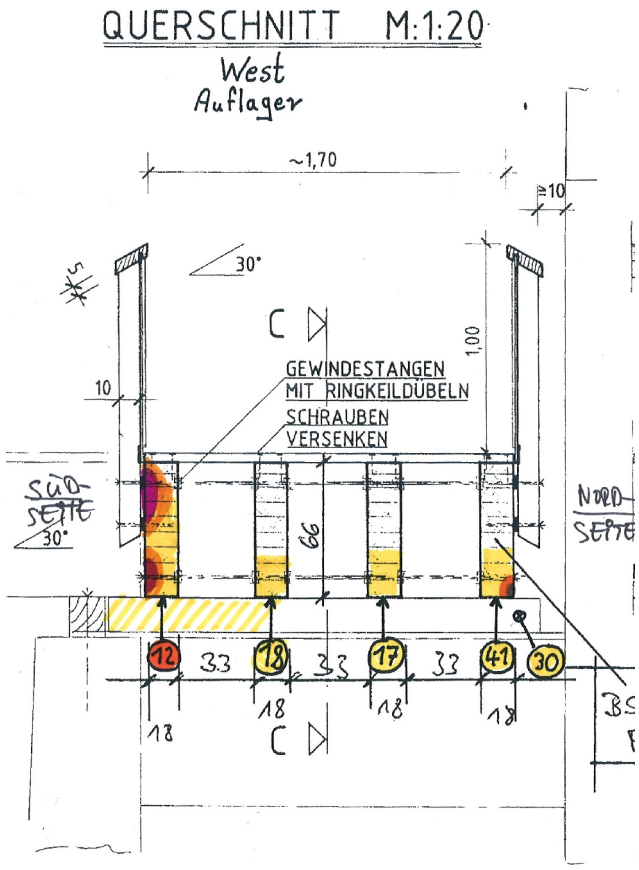


Visual damage sketch/map



Condition inventory



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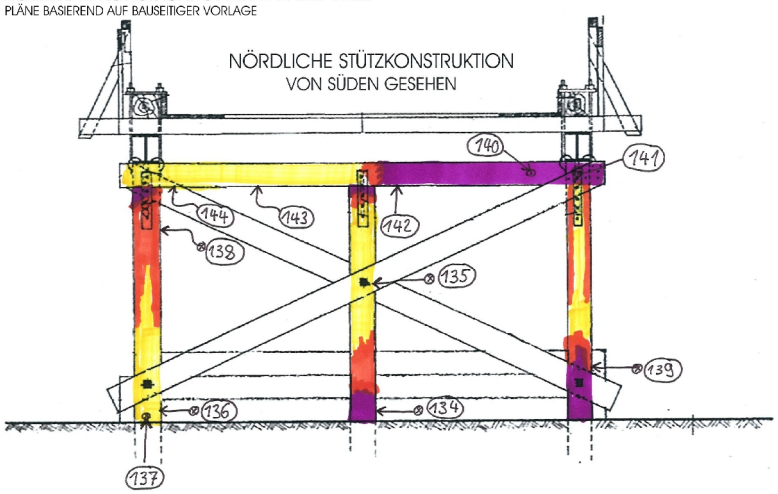

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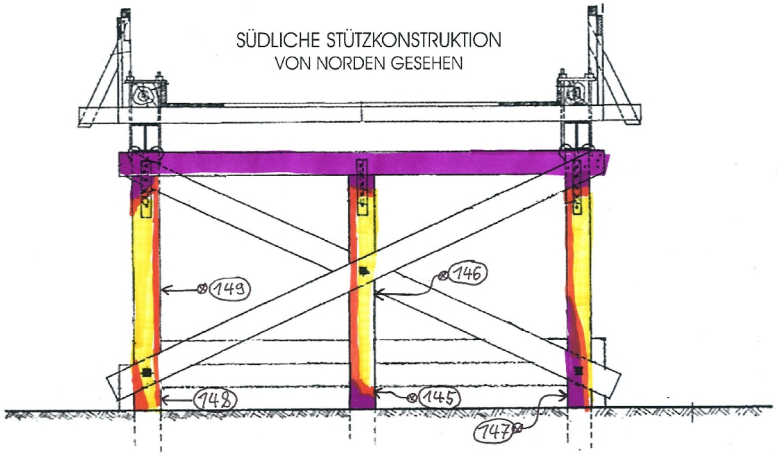

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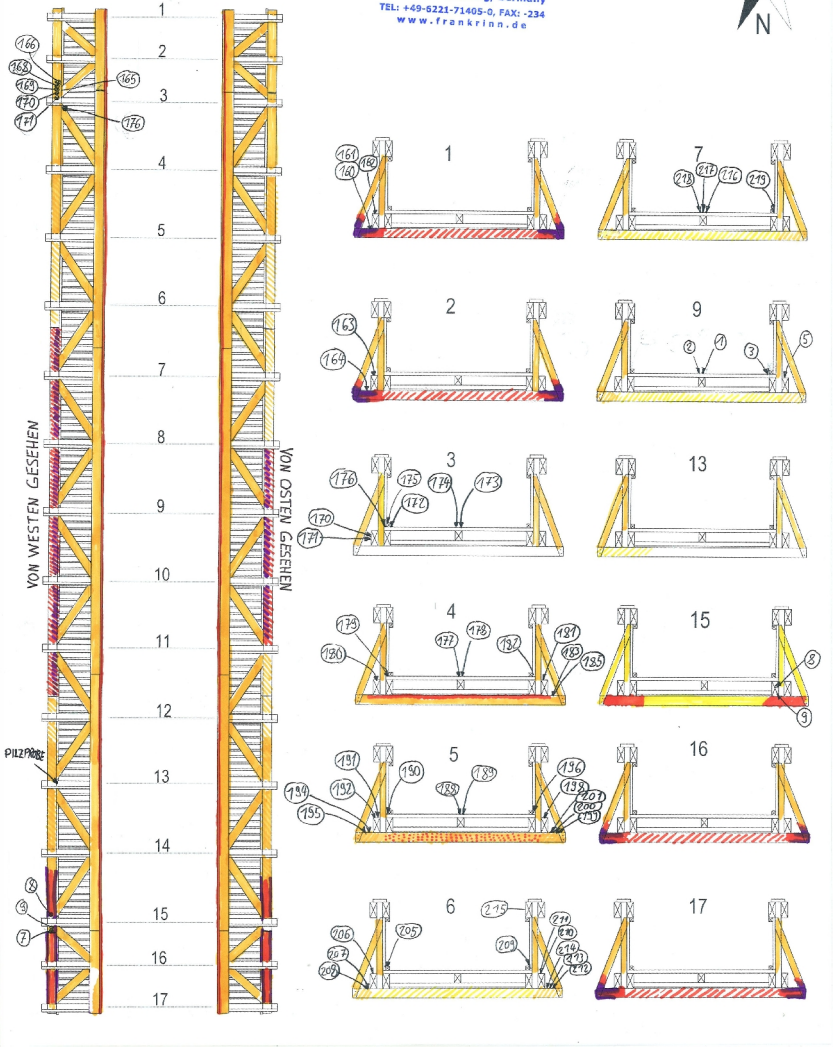

Summary and conclusions

- Properly designed timber bridges can last hundreds of years without significant damages (i.e. Bad Säckingen) but can deteriorate within 10 years if designed inappropriate.
- Combination of conventional inspection with technical methods, such as calibratable resistance drilling allowed comprehensive assessment and reliable evaluation of timber (structure) condition, by determining the (internal) condition of even hidden/invisible beams and connections.
- Resistance drilling through decks often saved up to 90% of inspection costs and time.
- Full documentation, clear and easy-to-understand presentation of results in color coded inventories support engineers, architects, and carpenters in planning and executing repairs while minimizing costs (and providing legally accepted proofs of the findings).
- Major achievements as compared to conventional maintenance/repair concepts:
  + higher planning safety (even complex projects): costs differ from budget <5%
  + average savings ~10x inspection costs ≈mostly >50% of normal total costs => ☺ ☹ !!

Thank you for your attention!

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Historic church roof structure built from oak beams in 1252 AD near Marburg, Germany:

Marking of identified decay on beams with chalk for demonstrating that although both beams look similarly intact and sounded intact, one of the ceiling beams is decayed internally due to recent fungal decay (after roof leakages).

Determining length and potential connection of beams (on walls) across buildings without taking off the floor (or stucco) with the use of stress-wave sensors.

If one ceiling beam reaches from one side of the building to the other, this means different load carrying capacities as compared to several beams connected on internal wall support points.

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