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Durability of cycle-pedestrian glulam footbridges.
From monitoring to Design for durability.

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Circular Bio-based Europe Joint Undertaking

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DIPARTIMENTO POLITECNICO DI INGEGNERIA E ARCHITETTURA

DURABILITY OF CYCLE-PEDESTRIAN GLULAM FOOTBRIDGES

FROM MONITORING TO DESIGN FOR DURABILITY

PH.D. ING. E. PEZ

TOPICS

- Typological characteristics of glulam footbridges
- Mechanisms of wood degradation
- Consequences of incorrect design, installation and maintenance
- Typical points of degradation
- Proposal for a quick comparison system for detailed design solutions according to maximum durability

CYCLE-PEDESTRIAN GLULAM FOOTBRIDGES

- A type of building that became very popular in the late 1990s and early 2000s due to the excellent properties of wood as a building material:
  - Building material with a very favourable ratio between mechanical strength and mass
  - Natural material suitable for any environment, especially natural ones
  - Natural repository of CO_2
  - Easily disposable


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CYCLE-PEDESTRIAN GLULAM FOOTBRIDGES: CRITICAL ISSUES

- A design phase that pays little attention to technological details in terms of durability leads to more costly maintenance requirements and/or premature loss of service.
- Failure to comply with maintenance programmes limits the life of the structure
- Premature loss of service contributes to the spread of a ‘bad reputation’ for wood as a construction material.

EXAMPLES OF MONITORED FOOTBRIDGES

- Approximately 15 years of effective service (subsequently closed as a precautionary measure)
- Finally completely demolished

EXAMPLES OF MONITORED FOOTBRIDGES

- Duration of less than 20 years
- Demolished without replacement

TYPES OF MONITORED FOOTBRIDGES

- ▷ Buildings of typically modest dimensions
- ▷ Various structural configurations
- ▷ Twenty-year monitoring period
- ▷ Visual inspections

Static scheme	Main structure					Parapet position					
						Timber			Steel		
	Timber beams and crossbars	Longitudinal steel beams and timber crossbars	Longitudinal timber beams and steel crossbars	Wooden crossbars only	Steel beams and crossbars	Joined to the crossbars	Joined to the glulam beam	Integrated in the beam	Inside the glulam beam	Above the glulam beam	Joined to the crossbars
Simply supported beam	■	■	■			■	■	■	■	■	
Multi- supported beam	■						■				
Simply supported curved beam	■		■	■			■	■	■	■	
Multi- supported curved beam	■		■		■		■	■			
Three-hinged arch	■		■					■		■	
Two/Three-hinged Arch with stiffening elements	■		■				■				
Reticular structure arch	■	■				■				■	
Tied arch	■		■			■	■	■			
Three-hinged arch with intermediate passway	■						■				
Truss bridges with buttresses	■					■					■
Two-span cable-stayed bridges	■		■						■		
Three-span cable-stayed bridges	■		■								■

TYPES OF TIMBER CYCLE-PEDESTRIAN FOOTBRIDGES

▷ Entirely timber-frame structure

▷ Partially timber-frame/mixed structure

TYPES OF TIMBER CYCLE-PEDESTRIAN FOOTBRIDGES

▷ Covered

▷ Uncovered

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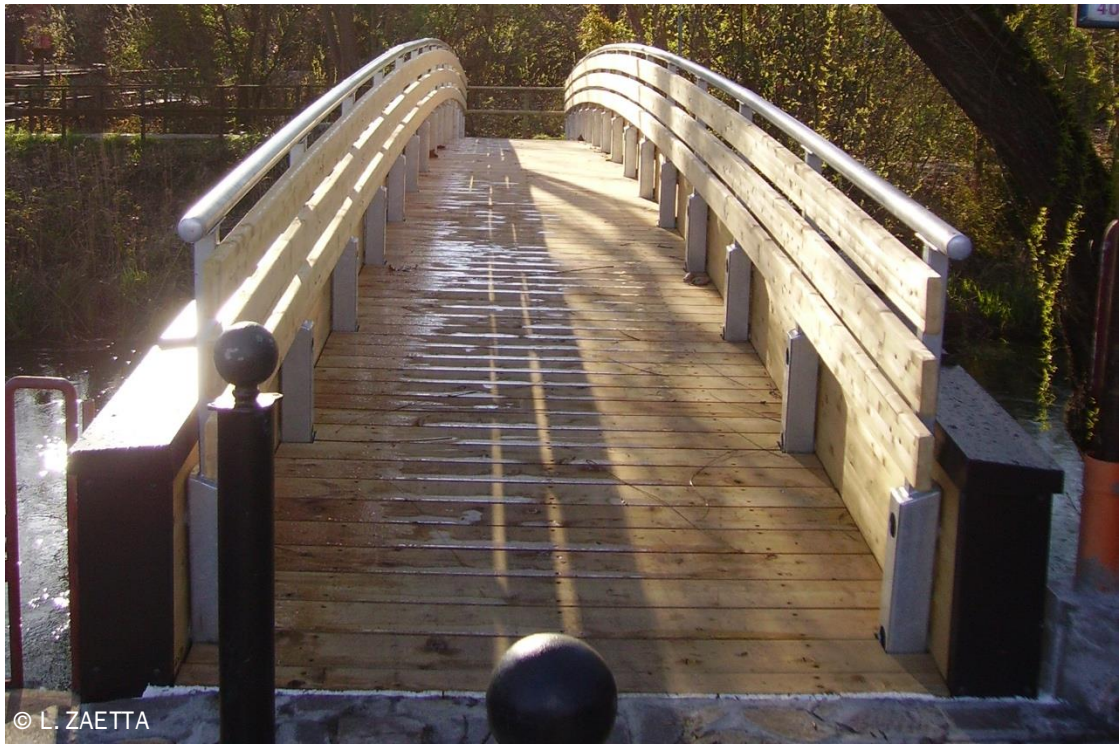

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TYPES OF TIMBER CYCLE-PEDESTRIAN FOOTBRIDGES

▷ Integrated parapet

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▷ Dedicated parapet

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DURABILITY

- Ability to perform as required, under given conditions of *use* and *maintenance*, until the end of *useful life*
- ISO 15686-1:2011 (*Building and constructed assets – Service life planning – part 1: General principles*): Capability of a building or its parts to perform its required function over a specified period of time under the influece of the agents anticipated in service
- For a product, to fulfill its functions (functionality, structural and fire safety, aesthetics..) over a given period under influece of degradation agents

DURABILITY OF WOOD COMPONENTS

- Environment (installation and operating conditions)
- Mechanical stresses
- Degrading agents

Durability of wood

- Natural durability
- Conferred durability

DURABILITY OF WOOD COMPONENTS

- In nature, wood, as an organic material, is broken down by different types of organisms:
  - Lignivorous fungi
  - Wood-eating insects
  - Bacteria
  - Marine borers
- Synergistic physical-chemical demolition of the substances that make up wood (cellulose, hemicellulose, lignin)

DURABILITY OF WOOD COMPONENTS

- *Natural durability* (EN 350:2016): inherent resistance of a wood species or a wood-based materiale agaist wood-decay organisms
  - Presence of natural components with different levels of toxicity towards biological organism
  - Anatomical particularities
  - Specific constitution (wood based materials)

DURABILITY OF THE MOST COMMON TIMBER SPECIES (EN 335)

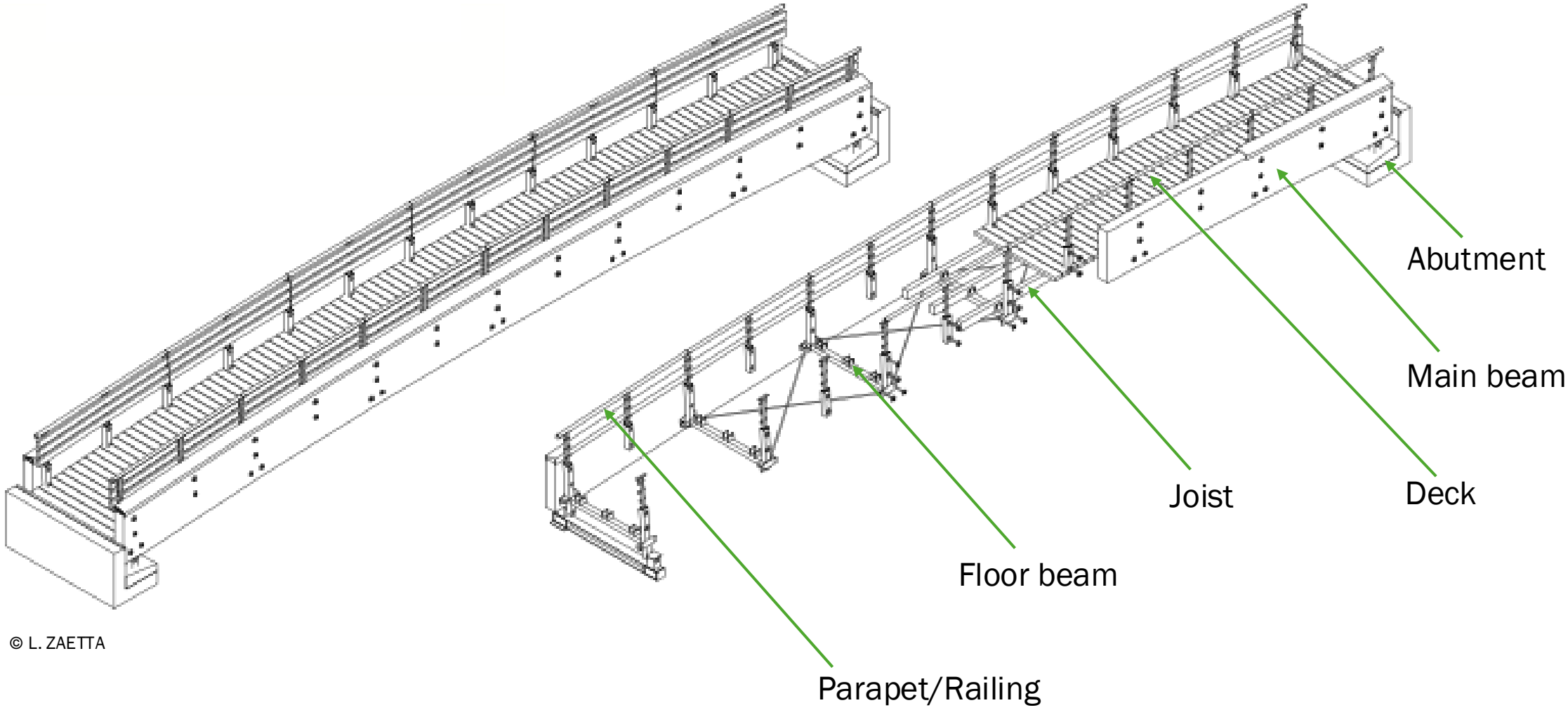
Name	Heartwood durability			Impregnability	
	Basidiomycetes	Hylotrupes	Anobium	Heartwood	Sapwood
Fir	4	S	S	2-3	2v
Norway Spruce	4	S	S	3-4	3v
Larch	3-4	D	D	4	2v
Redwood	3-4	D	D	3-4	1

Natural durability: D (*durable*) – S (*not durable*)
Impregnability: 1 (*easily impregnable*) – 4 (*very difficult to impregnate*)
V: high level of variability in the data

DURABILITY OF WOOD COMPONENTS

- *Conferred durability* (EN 460:2023): Improved resistance of a wood species to biological degradants provided by a treatment process (chemical, physical, etc.) such as wood preservation or wood modification.
  - Surface treatments (less effective)
  - Pressure treatments
  - Permanent modification treatments (more effective)

CYCLE-PEDESTRIAN FOOTBRIDGES – MAIN COMPONENTS



MAIN CRITICAL ISSUES

▷ Main beam – ground contact

MAIN CRITICAL ISSUES

▷ Contatto travi principali - terreno

MAIN CRITICAL ISSUES

- Deck boards – beams contact
  - Debris accumulation near horizontal surfaces, spaces and boards heads

MAIN CRITICAL ISSUES

▷ Metal-wood connection contact

MAIN CRITICAL ISSUES

▷ Water accumulation on horizontal surfaces

MAIN CRITICAL ISSUES

▷ Unprotected vertical surfaces

MAIN DEGRADATION POINTS IN SAMPLE TIMBER FOOTBRIDGES

Building element	Main degradation type	Main degradation effects	Deterioration causes			
			Environmental and external phenomena	Anthropogenic agents		
				Design	Production / Construction	Maintenance
Main beam support	Marcescence	Reduced cross-sectional area near the head of the beams	Timber-ground contact	■		■
Deck	Marcescence	Early loss of service	Accumulations of wet material near the element heads and in the interspaces	■		■
Beams upper surface	Colour alteration / cracking	Stagnation and water penetration	Meteoric agents	■		■
Beams side surfaces	Colour alteration / cracking	Possible delamination, cracks and water stagnation	Meteoric agents		■	■
Connections distribution and installation	Cracking	Cracks, crushed fibres, colour changes	Timber-metal contact	■	■	

CYCLE-PEDESTRIAN GLULAM FOOTBRIDGES: REQUIREMENTS

- The service life of footbridges should be at least 50 years: many of the footbridges monitored have shown serious problems and required costly repairs even before reaching 10 years of operation.
- For proper design in terms of durability, it is necessary to clearly identify the boundary conditions (exposure) to which the various components of the walkway will be subjected.

EXPOSURE CLASSIFICATION: SERVICE CLASSES (EN 1995-1:2004)

Service Classes	Moisture content of wood (reference values for most softwoods)	Environmental conditions
SC1	≤ 12%	Temperature 20 °C, relative humidity of surrounding air > 65% for a few weeks per year
SC2	≤ 20%	Temperature 20 °C, relative humidity of surrounding air > 85% for a few weeks per year
SC3	> 20%	Higher moisture content than class SC2

▷ «*The service class system is mainly aimed at assigning strenght values and for calculating deformations under defined environmental conditions.*»

EXPOSURE TO DEGRADING AGENTS CLASSIFICATION: USE CLASSES

Use Class	Moisture content of wood		General service condition	Biological degrading agents		Footbridge Components
				Fungi	Insects Marine borers	
UC 1	Always < 20%		Interior, dry	-	Termites Beetles	-
UC 2	Occasionally > 20%		Interior/Under cover, not exposed to the wheater, possibility of water condensation	Ascomycetes Basidiomycetes	Termites Beetles	Roof beams (covered footbridges)
UC 3	Regularly > 20% Not in ground or water	3.1 Limited humidification	Exterior, above ground, exposed to the weather	Ascomycetes Basidiomycetes	Termites Beetles	Floor planks Cladding elements Main beams Railings
		3.2 Prolonged humidification		Ascomycetes Basidiomycetes	Termites Beetles	Floor planks, near heads Joists Main beams, near points of contact with the ground

EXPOSURE TO DEGRADING AGENTS CLASSIFICATION: USE CLASSES

Use Class	Moisture content of wood	General service condition	Biological degrading agents		Footbridge Components
			Fungi	Insects Marine borers	
UC 4	Permanently > 20%	Exterior, in ground contact and/or fresh water	Ascomycetes Basidiomycetes Softrot	Termites Beetles	Pillars
UC 5	Permanently in seawater	Permanently or regularly submerged in salt water	Ascomycetes Basidiomycetes Softrot	Termites Beetles Marine borers	Pillars

SERVICE - USE CLASSES POSSIBLE CORRELATION (EN 335:2013)

Service Classes	Use Classes
SC1	UC1
SC2	UC1 UC2 (Occasional humidification of the component, e.g. condensation moisture)
SC3	UC2 UC3 (Classes even higher if component is placed outdoor)

DESIGNING DURABILITY IN FOOTBRIDGES (EN1995-2:2004)

- Covering structural timber elements when possible
- If not, durability can be increased through :
  1. Designing surface geometry to prevent stagnation and remove any water that may have accumulated
  2. Preventing cracks and cavities
  3. Preventing capillary absorption with appropriate barriers
  4. Promoting natural ventilation of all wooden parts
  5. Limiting humidity variations by choosing a material humidity as close as possible to the service conditions

AVOID GROUND CONTACT: SOME DESIGN CONSIDERATIONS

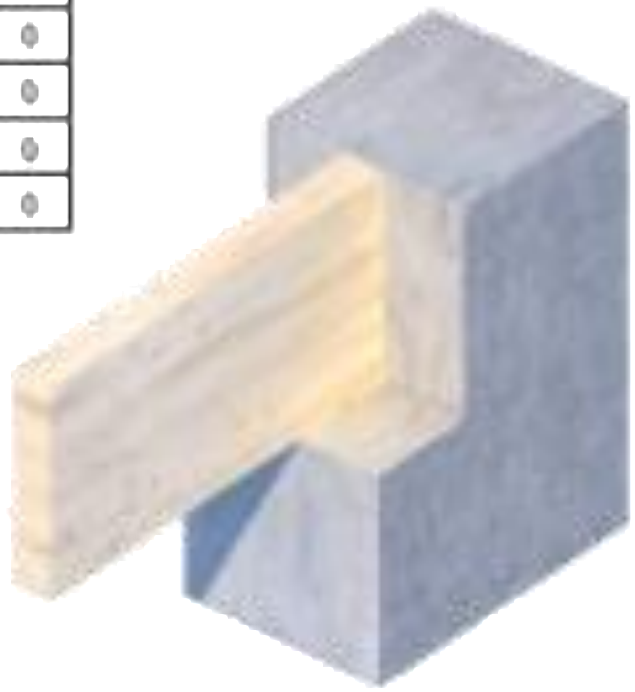
- Elevation of wooden parts
- Abutment modelling for water drainage
- Wood-metal and wood-concrete decoupling
- Beam head ventilation

AVOID WATER CONTACT : SOME DESIGN CONSIDERATIONS

- Beam head cladding
- Waterproof coating of the contact surface between deckboards and joists
- Natural ventilation of deck boards ends

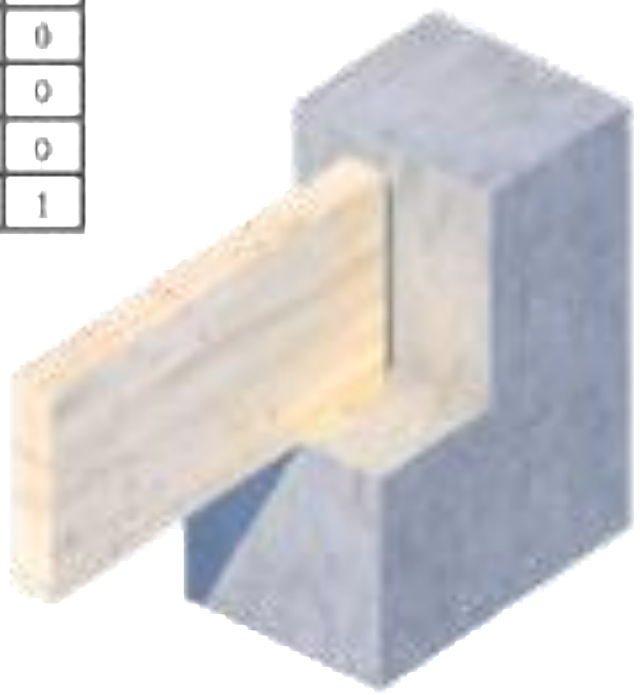
DESIGN FOR DURABILITY: CONTACT BEAM-GROUND

D1	0
D2	0
H	0
R	0
	0



Direct support and head contact of the beam

D1	1
D2	0
H	0
R	0
	1



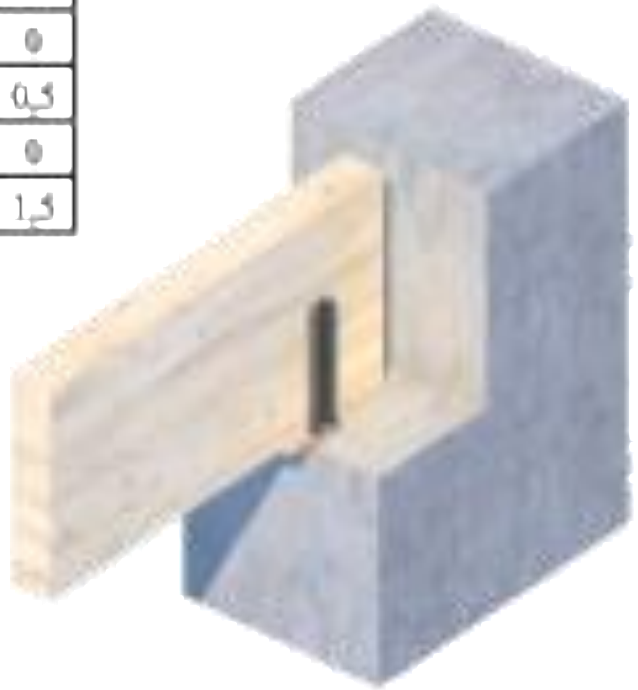
Direct support and head contact of the beam

Evaluation of performance to individual factors:

D1 - direct runoff
D2 - indirect runoff
H - stagnation and infiltration moisture
R - solar radiation

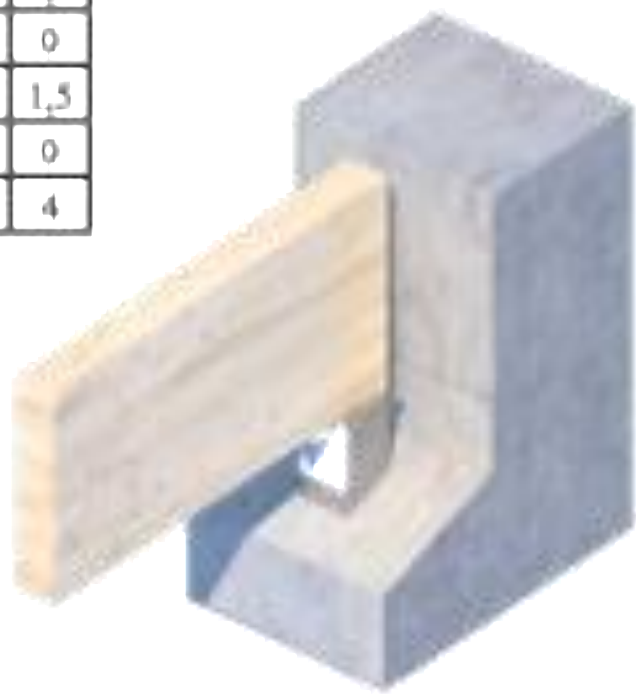
DESIGN FOR DURABILITY: CONTACT BEAM-GROUND

D1	1
D2	0
H	0,5
R	0
	1,5



Indirect support with minimum elevation

D1	2,5
D2	0
H	1,5
R	0
	4



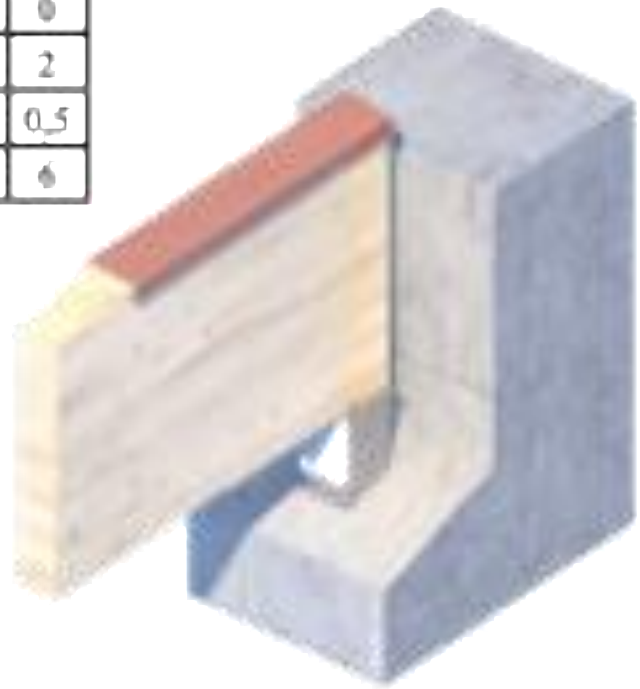
Elevated support with inclined edge for water detachment

Evaluation of performance to individual factors:

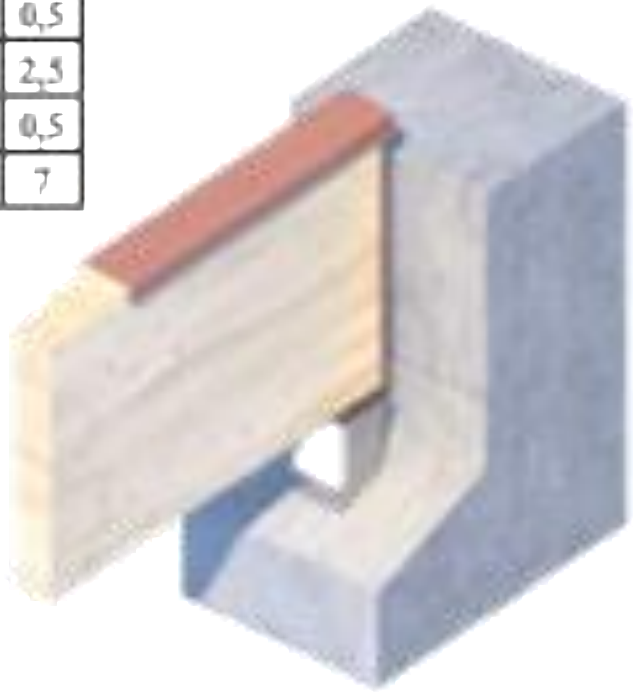
D1 - direct runoff
D2 - indirect runoff
H - stagnation and infiltration moisture
R - solar radiation

DESIGN FOR DURABILITY: CONTACT BEAM-GROUND

D1	3,5
D2	0
H	2
R	0,5
	6



D1	3,5
D2	0,5
H	2,5
R	0,5
	7



Evaluation of performance to individual factors:

D1 - direct runoff
D2 - indirect runoff
H - stagnation and infiltration moisture
R - solar radiation

Elevated support and top protective cover

elevated support with insulating element between wood and metal and top and top protective cover

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