IPHA TECHNICAL SEMINAR 2017
October 25–26. Tallinn, Estonia

Design aspects of finished elements

Jaime Fernández Gómez
Technical University of Madrid/SEG | Spain

Organized by

IPHA
INTERNATIONAL PRESTRESSED HOLLOWCORE ASSOCIATION

in cooperation with

eesti betooniühing

EESTI EHITUSINSENERIDE LIIT

supported by

fib CEB-FIP

Design Aspects of Finished Elements

Prof. Jaime Fernández-Gómez
Full Professor on Building Construction and Prefabrication. Polytechnic University of Madrid. Vice-Chairman of SEG

Content

1. Quality control as a tool to avoid defects
2. Dimensional tolerances
3. Slippage of prestressing tendons
4. Treatment of imperfections
   - Safety
   - Constructional purposes
   - Aesthetics
5. Full-scale loading tests

1. Quality control system

- It must include all activities
- Accepted by Manager
- Carried out by personnel not involved in production
- Written programme
- Need for continuous improvement
- Need to be realistic

Quality control programme

- Organization chart and relations among personnel
- Monitoring by the management. Annual revision
- Equipment
- Procedures:
  - Purchases
  - Calibration
  - Inspection reports
  - Reports
  - Production
  - Tolerances
  - Erection
- Treatment of deviations

Written procedures

- Material receipt
- Sampling and testing
- Drawings: checking and approval
- Product checking
- Production, storage and transportation
- Prestressing
- Mix design
- Concrete sampling and testing
- Final inspection of finished products
- Repair of non-conforming products
- Record of quality control operations
- Equipment maintenance and calibration

Inspections

- Constituent materials and products
- Moulds
- Reinforcing
- Tensioning and detensioning
- Concreting and curing
- Demoulding and storage
- Finished products
- Final record of products

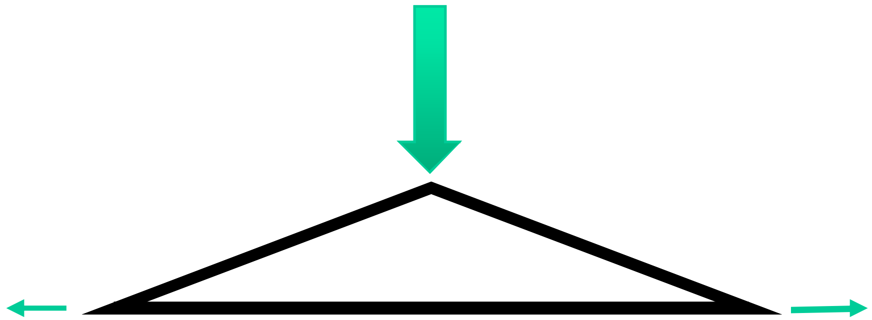
Example of quality control procedures

Automatic prestressing. In this case, 13 Tn.
The jack stops at specified load, and does not allow a different one to be applied

Checking the prestressing load by calibrated gauges

General inspection before concreting

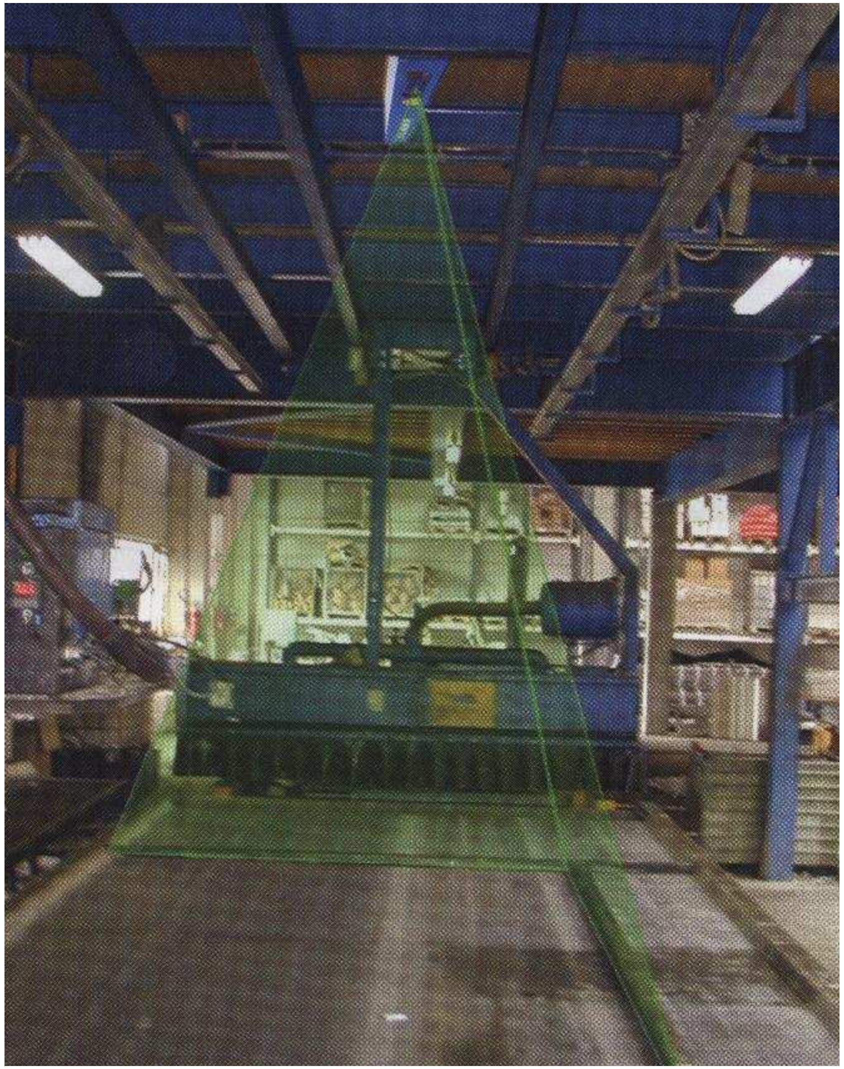
Checking prestressing on strand



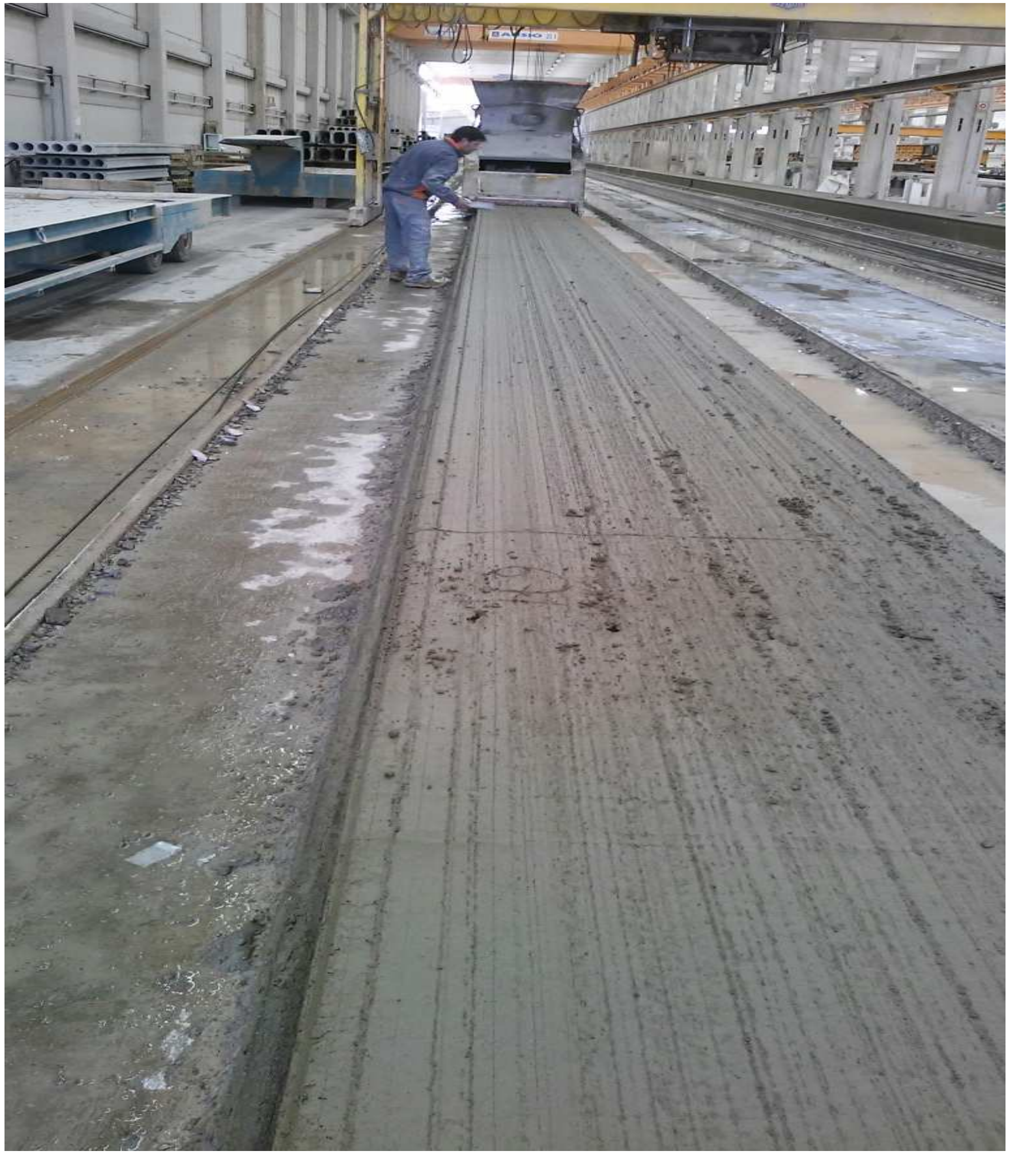
Checking the reinforcement position in several sections along the length

Concreting. Checking the operations

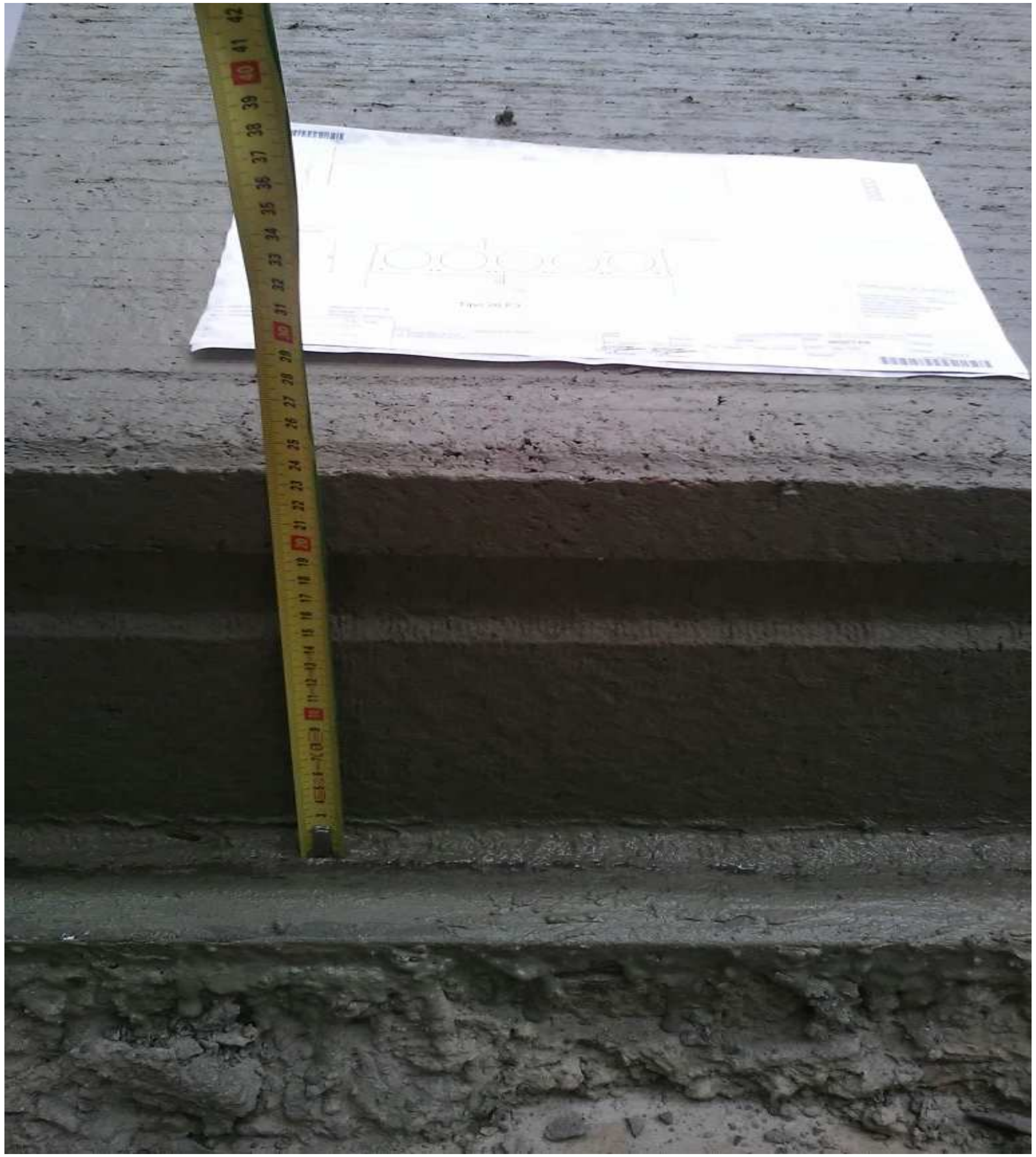
Automatic laser marking



After concreting, checking dimensions in several sections along the length



After concreting, checking dimensions in several sections along the length



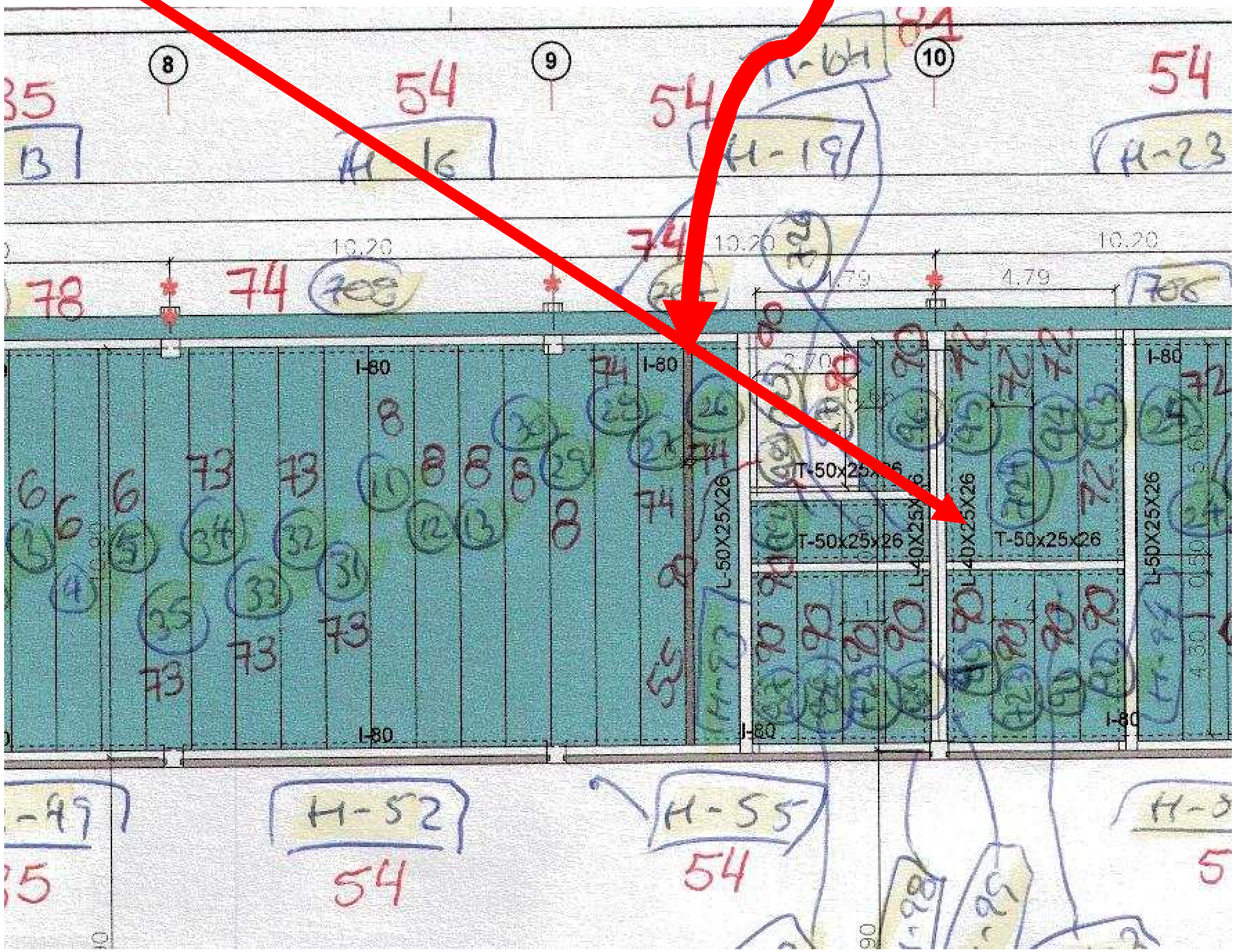
Identification and capping the end of the cores

Concrete assesment. Specimens

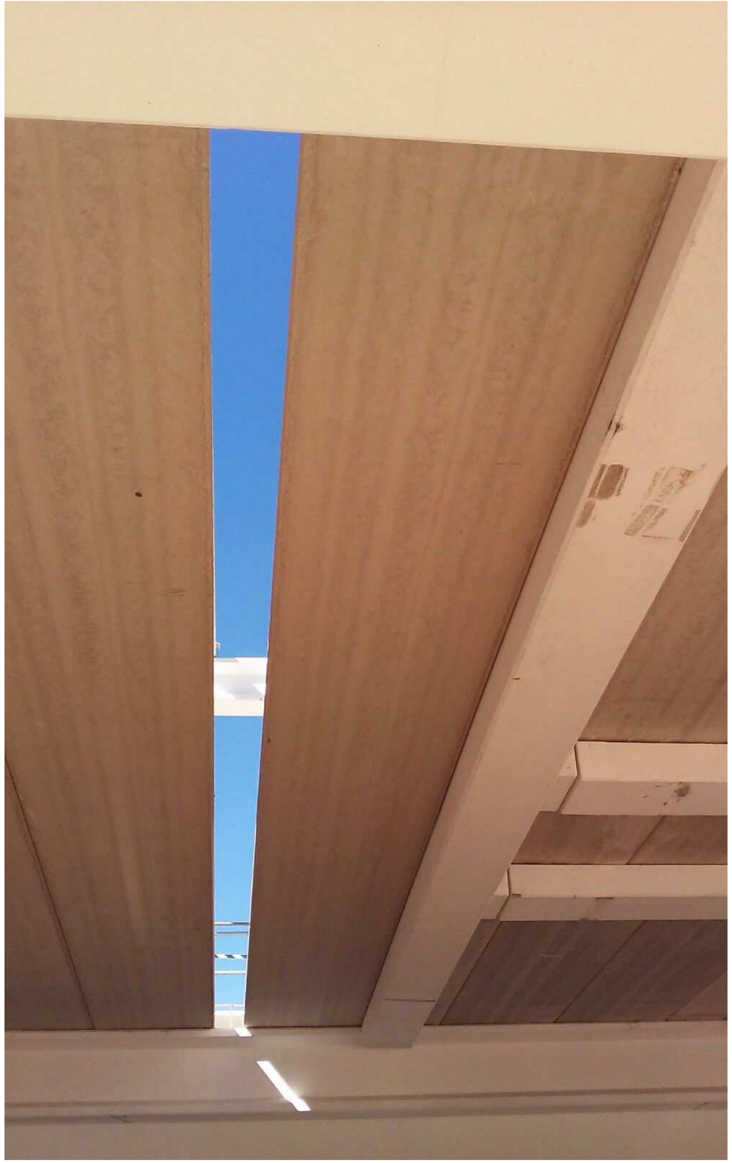
- Use of cubic specimens or cylinders with polishing capping
- Equivalent coefficients to transform cube strength in cylinder strength

Construction drawing with adjustment area. Definition of element, number and lorry identification

Layout thought for opening big holes in the future



Building situation



To open big holes in the future

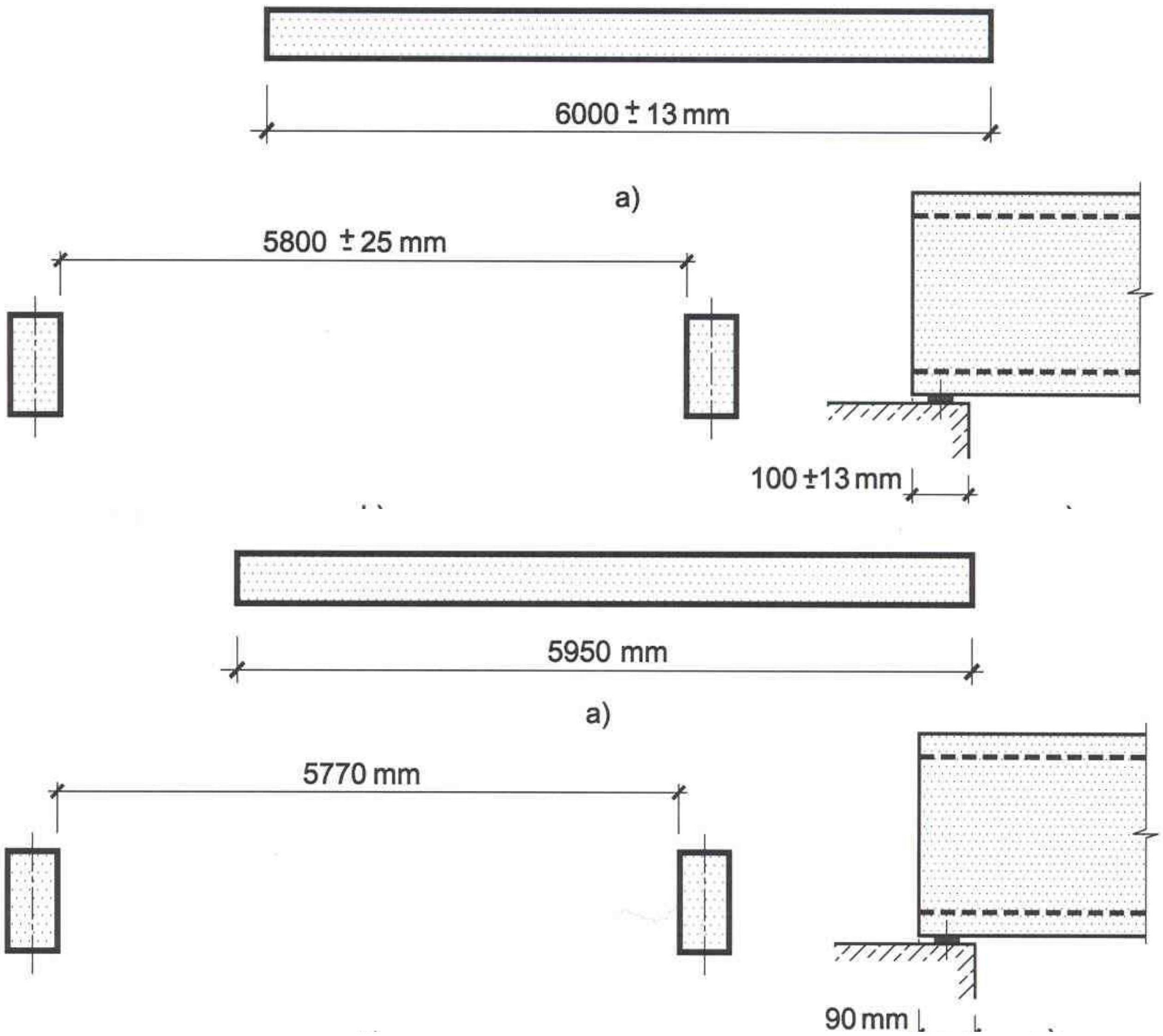
2. Dimensional tolerances

- Two types of tolerances:
  - Manufacturing tolerances, depending on manufacturing processes (length, width,among others)
  - Building tolerances, associated with incorporating the components into de building structure (dimensions between supports, support length,among others)
- Manufacturing tolerances are divided into structural and non-structural

Practical application of tolerance systems

- Existence of good manuals of tolerances
  - PCI, ACI
- EN standards do not define acceptance criteria
- Need for good judgement and practical experience
- In many cases, tolerances defined in projects are extremely difficult to comply with
- There is no need for stricter tolerances than actually needed
- Look at the problem, taking into account the overall effect on construction

Example of building tolerances



Dimensional Tolerances

Item		Minimum	Maximum	Remark
Length (*L*)		- 25 mm	+25 mm	
Width (*b*)	Whole slab	- 5 mm	+5 mm	
	Narrowed slab	–25 mm	+25 mm	
Slab depth (*h*)	*h* ≤ 150 mm	- 5 mm	+10 mm	The slab height has a direct influence on the flexural and the shear capacity of the slab
	150 < *h* < 400 mm	Linear interpolation		
	h ≥400 mm	- 10 mm	+15 mm	
Min. web thickness (*bw*)	Individual web	- 10 mm		The web thickness is influencing the shear and torsion resistance of the slab
	Total per slab	- 20 mm		
Minimum flange thickness (above and underneath the cores) (*f*)	Individual flange	- 10 mm	+ 15 mm	The flange thickness is influencing the resistance against fire, torsion and point loads
	Average flange	- 5 mm		

Dimensional Tolerances

Item		Minimum	Maximum	Remark
Position of prestressing tendons (*c*)	*h* ≤ 150 mm	- 5 mm	+ 5 mm	Furthermore, requirements on minimum cover should be respected
	150 < *h* < 400 mm	Linear interpolation		
	h ≥ 400 mm	- 10 mm	+10 mm	
	Centre of gravity for total slab	-5 mm	+8 mm	
Minimum support length (*ℓs*)	*h* < 400 mm	60 mm		Will be dependent on building tolerances
	h ≥ 400 mm	80 mm		
Orthogonality (*g*)		-10 mm	+10 mm	Deviation from orthogonality of slab
Sweep (s)	*L* ≤ 12 m	-5 mm	+5 mm	
	L > 12 m	-10 mm	=10 mm	
Openings, block- outs	Location in fresh concrete	-25 mm	+25 mm	
	Location in hardened concrete	-15 mm	+15 mm	
	Size in fresh concrete	-20 mm	+50 mm	
	Size in hardened concrete	-20 mm	+30 mm	

Slippage of prestressing tendons

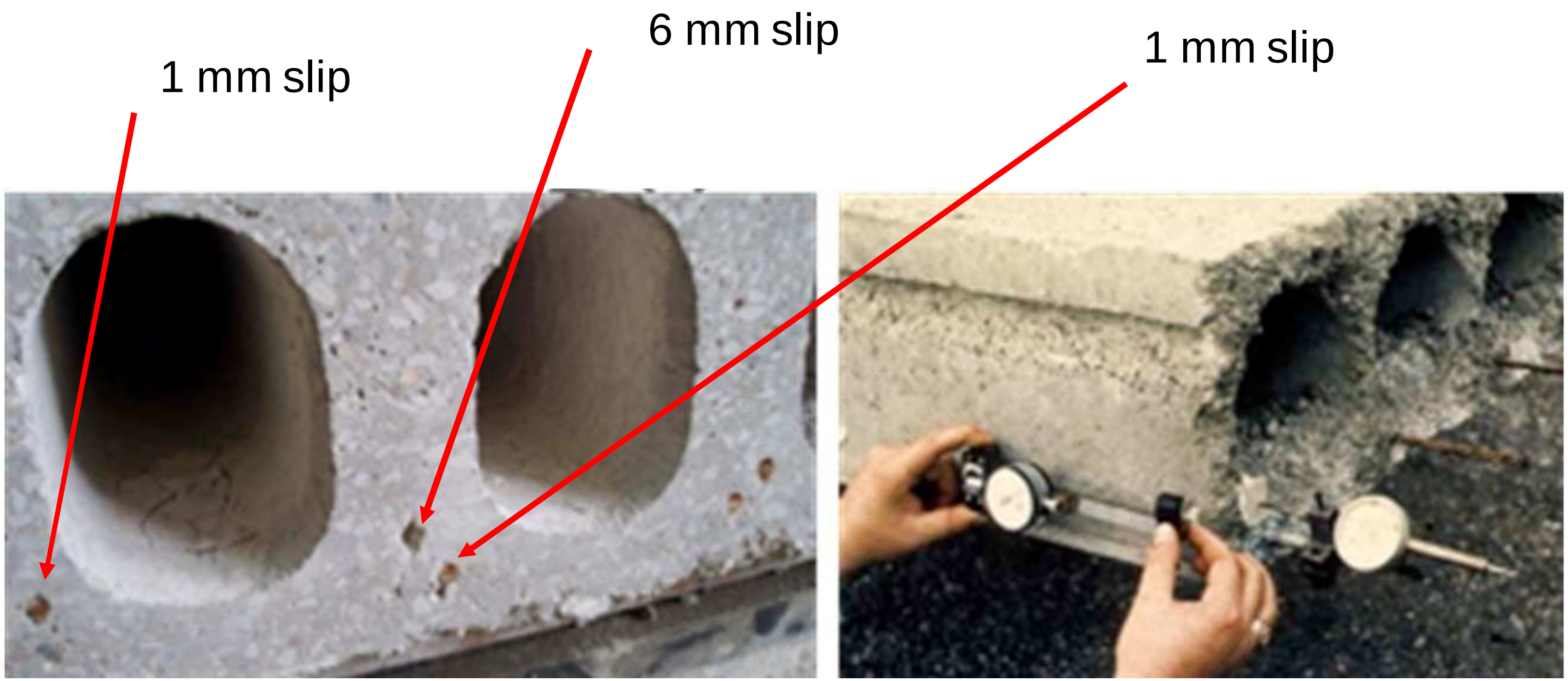
- Example:
  - 12.5 mm diameter strand
  - l_{pt_2}= 50 Ø
  - Prestressing stress: 1177 N/mm^2
  - $\Delta l_0 = 1.5$ mm
- Knowing the slippage, $\mathrm{l_{pt_2}}$ can be calculated
- Shear capacity can be assessed
  - $V_{Rd,c} = \frac{I \cdot b_w}{S} \sqrt{(f_{ctd})^2 + \frac{l_x}{l_{pt_2}} \sigma_{cp} f_{ctd}}$

3. Slippage of prestressing tendons

- Relation with transmission length
- Maximum allowable bond slip should be considered in assessing the shear capacity
- Strand slippage
  - $\Delta l_0 = \beta l_{pt_2} * \frac{\sigma_{p0}}{E_P}$
  - $\beta =$ Prestress coefficient ≈ 0,4
  - $l_{pt_2=}$ upper bound value of transmission length
  - $\sigma_{p0=}$ prestressing stress immediately after release
  - $E_P =$modulus of elasticity
- Limit values given in EN 13369
  - Individual tendons= 1,30 Δl_0
  - Mean value of all tendons= 1,0 Δl_0

Slippage of prestressing tendons

- First check may be performed vissualy
- If needed, check the slippage of each strand



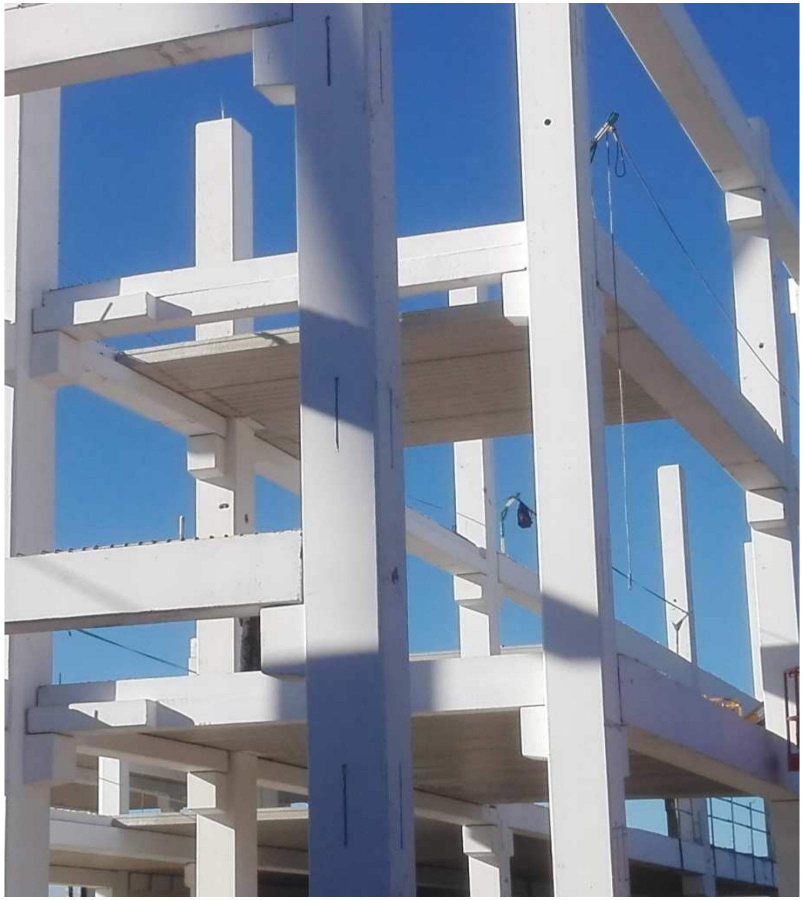
4. TREATMENT OF IMPERFECTIONS

Task Group 6.8 of FIB Commission 6 Prefabrication
“Treatment of Imperfections in precast concrete structural elements”

- Convener
  - José Calavera, Spain
- Members
  - Kamel Bensalem, England
  - Sébastien Bernardi, France
  - Barry C. Crisp, Australia
  - Jaime Fernández, Spain
  - David Fernández-Ordóñez, Spain
  - Nordy Robens, Belgium
  - Aarto Suikka, Finland (†)
  - Arnold van Acker, Belgium
  - Aad van Paassen, The Netherlands

Acceptance and rejection

- Difficulties of rejection precast structural elements
  - Economic importance of units
  - Problems of delivery and delays
- Difficulties in analysing flaws in ways not normally addressed in technical codes
- To establish routine procedures (production and acceptance) for handling defects



Scope of FIB Document

- Evaluation of imperfection of precast concrete elements that do not meet the quality intended in design
- Provision of rules and possible evaluation systems
- Recommendations for the following
  - Prevention
  - The effect the imperfections can have
  - Actions for rectification
- The document should be read in conjunction with relevant codes and standards

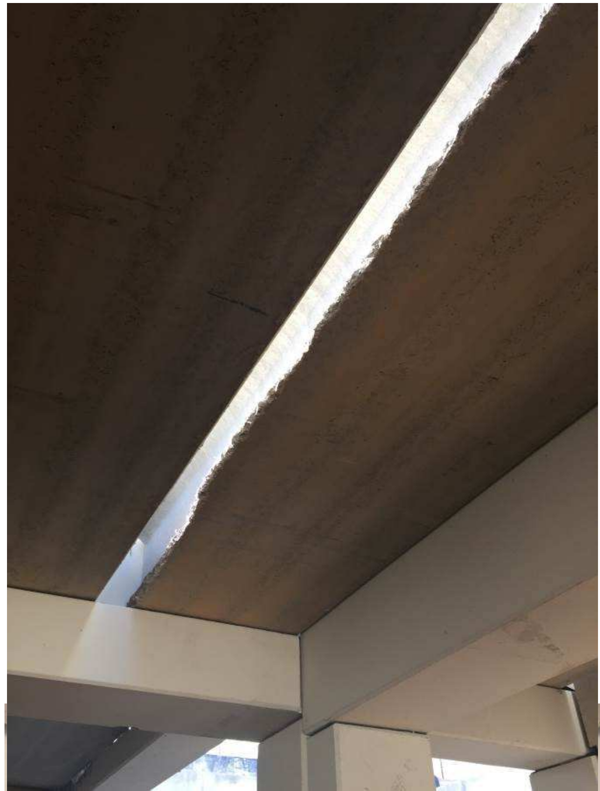
Types of Defects

- Dimensional deviations
- Surface and aesthetics
- Surface flatness
- Colour and Colour variations
- Cracking
- Deflection and Camber
- Cracks
- Spalling, splitting and bursting
- Accidental damage

Segregation

Casting problems

Longitudinal crack above core



Problems in adjustment area. Different possibilities of solution. Relation with design

Storage stains.
Clean with pressured water on site

Wire slipping

Transference cracks

Accidental damages

Colour defects. Hollow cores used as panels

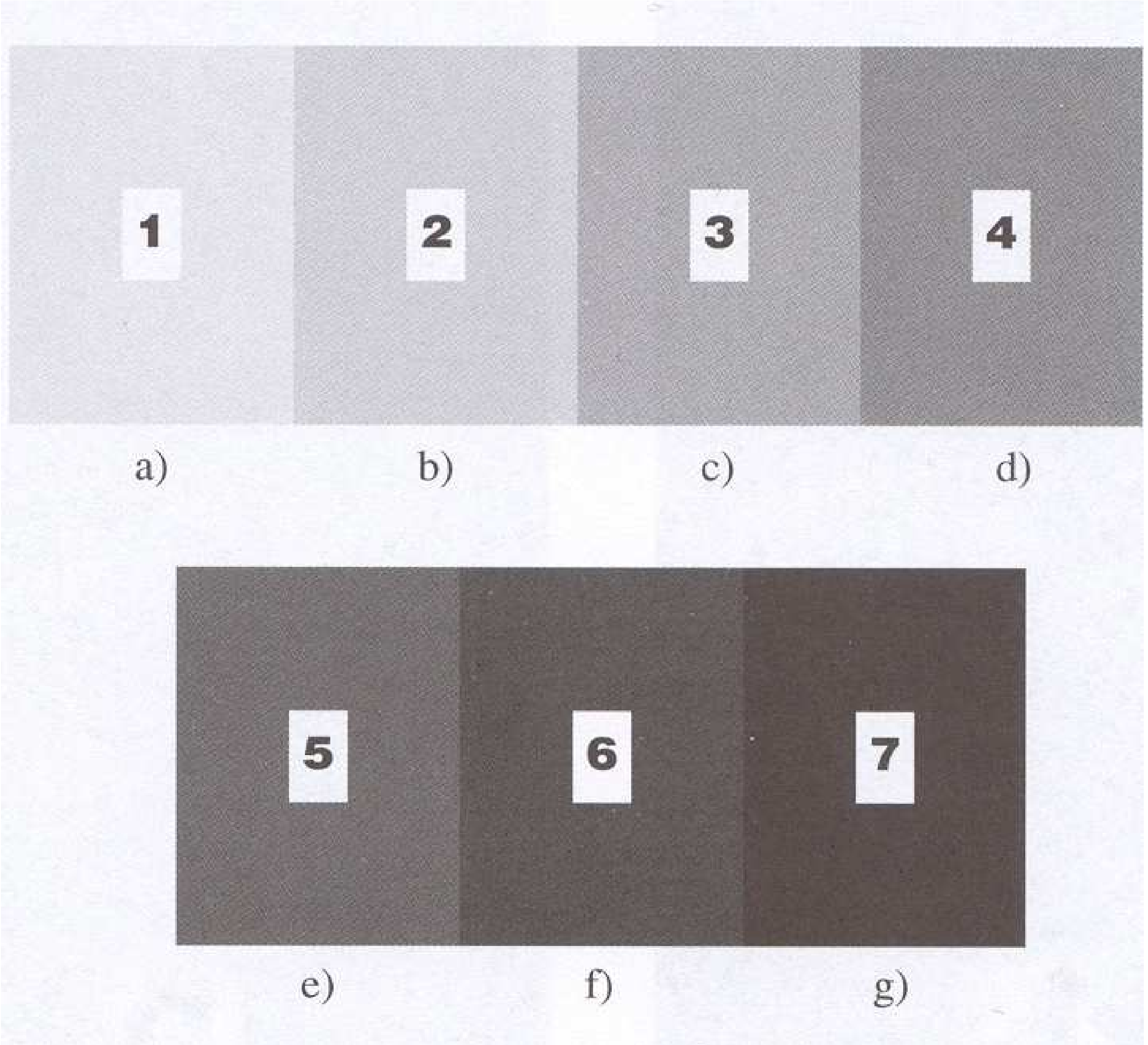
General cracks

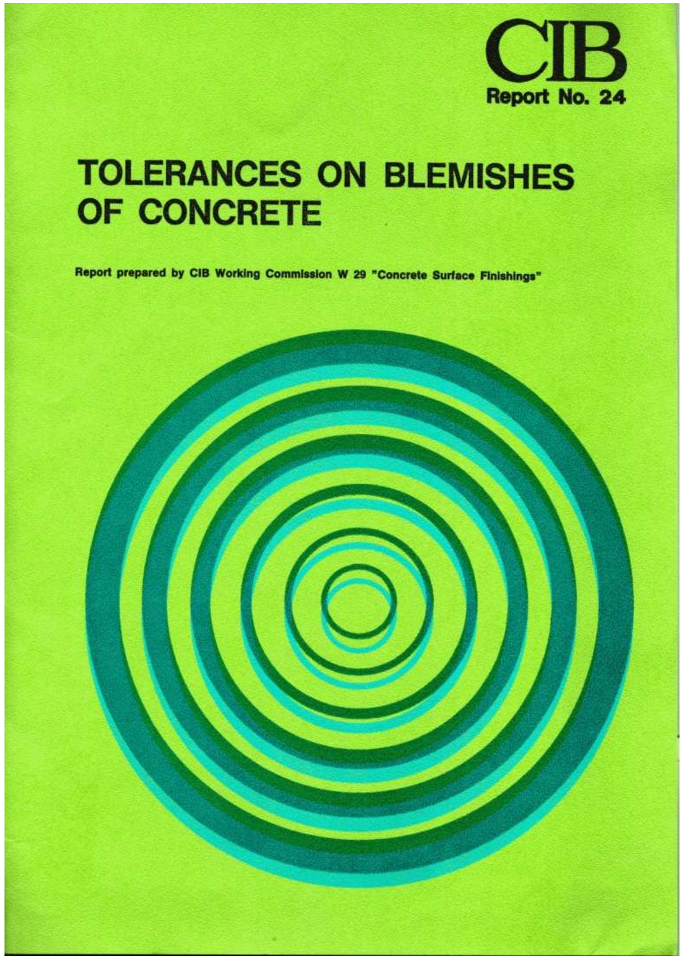
- Inherent in reinforced concrete
- Different causes
  - Thermal cracks
  - Plastic settlement and autogenous shrinkage
  - Drying shrinkage
  - Mechanical cracks
    - Handling problems
    - Spalling, splitting and bursting
    - Due to stresses
  - Always analyse the consequences in safety and durability. Example about how to evaluate safety included in the appendix of the FIB document

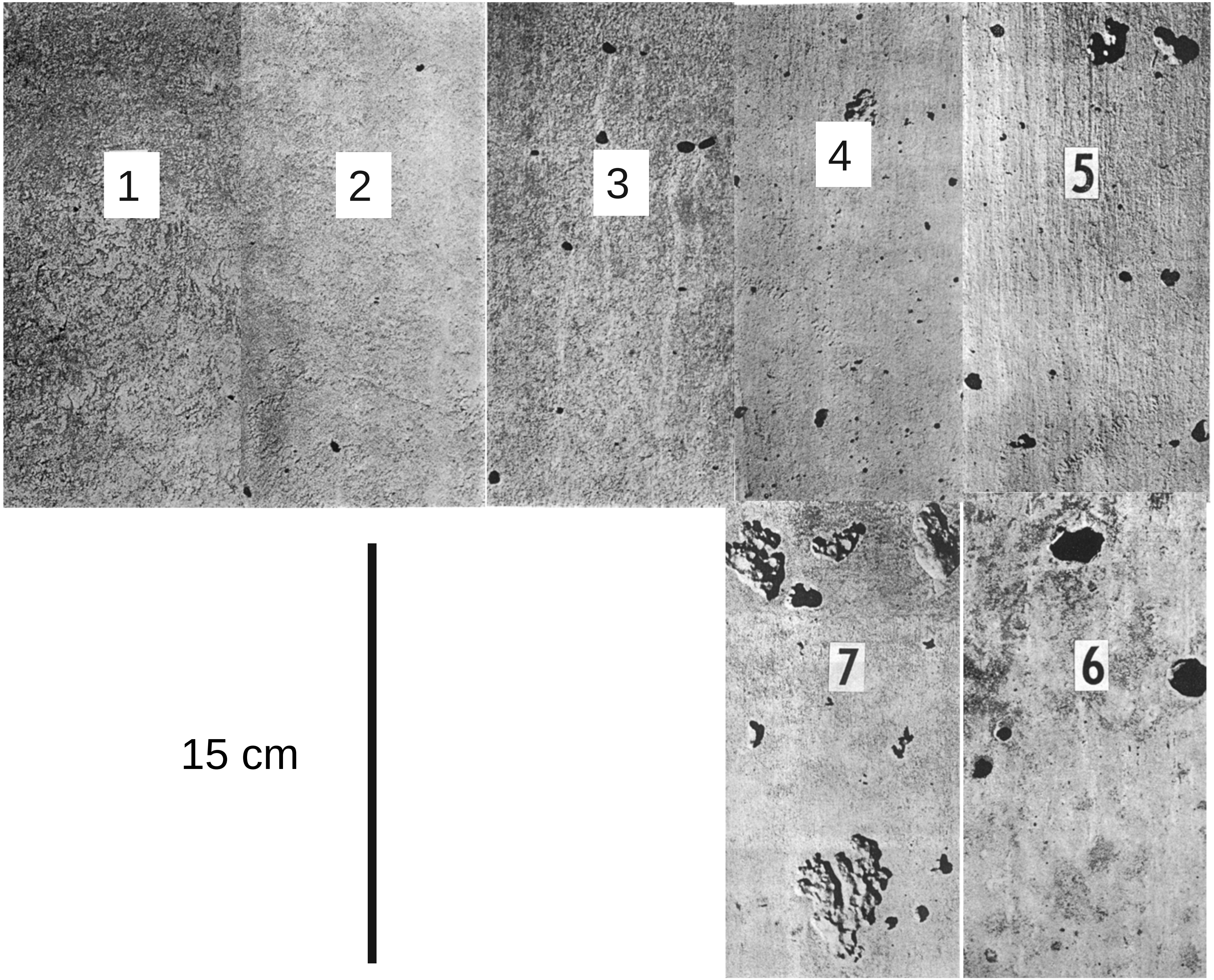
Maximum size and amount of visual cracks in concrete surfaces

Surface treatment	Class AA	Class A
Light mould surface, steel rubbed, fine washed aggregate, low sand blast or acid treated surface	not allowed	0,1 / 500
Dark mould surface, timber rubbed, brushed or medium sandblasted surface	0,1 / 500	0,2 / 500 0,1 / 1000
Washed aggregate or deep sandblasted surface	0,2 / 500	0,2 / 1000
Coated surfaces		
Inside structure		0,2 / 1000 0,1 / 5000
Outside structure		0,3 / 3000 0,2 / 5000

Grey colour classification according to CIB report Nº 24






1
2
3
4
5
7
6
15 cm

Hollowcore prices

Price (€/m^2)		Depth (cm)
Manufacturing	Total (200 Km)	
27	33	20
65	80	50

Crack injection prices

Price (€/m)		Equipment displacement
Preparation	Injection + material	
42	55	300

Pressured hydrocleaning

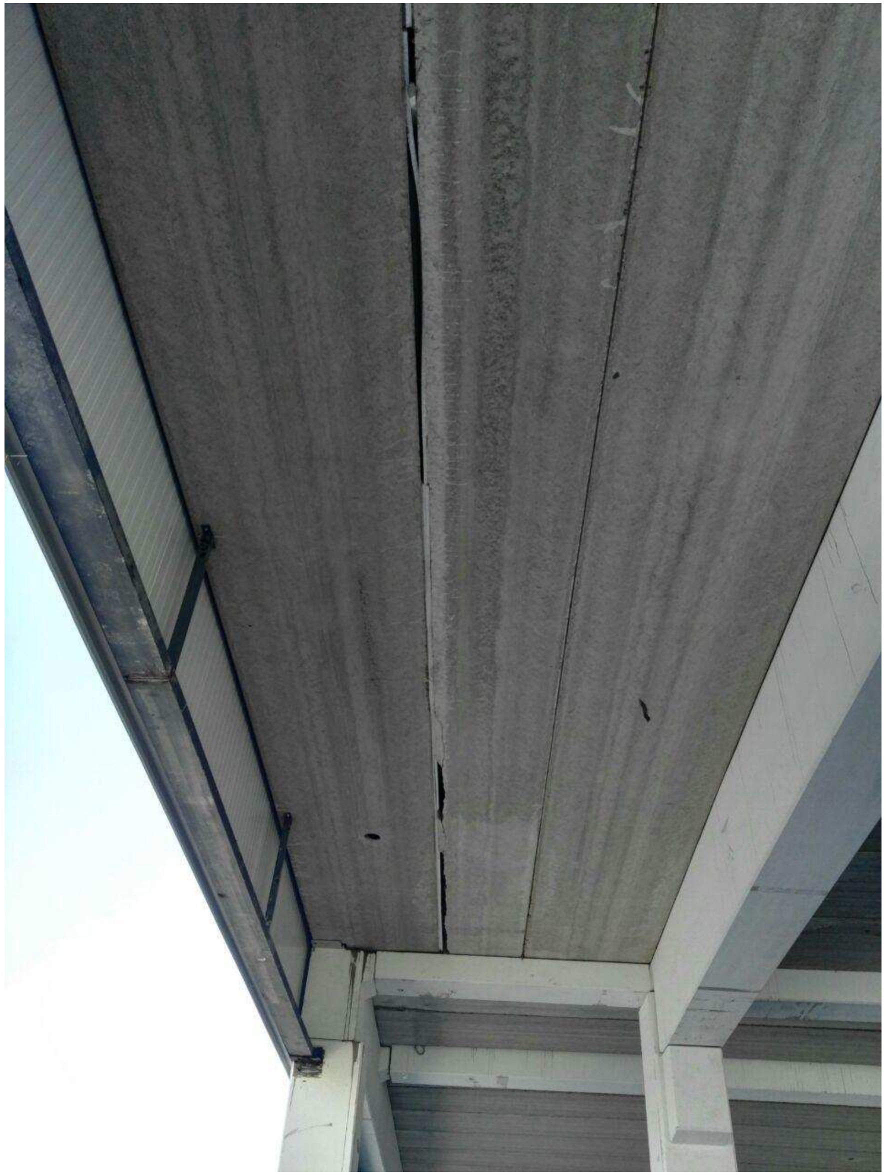
Price (€/m^2)	
Cleaning	Equipment displacement
10	500

Practical application of repair decisions

- A normal unit (10 m^2) costs €270-650
- Do not take risks in relation with safety
- A repair must be something simple, easy and inexpensive, and one that solves the problem
- Aesthetical repairs can be performed onsite, taking into account the general problem
- Longitudinal cutting, in order to obtain a small unit, can be a general procedure for not acceptable elements
- Injecting cracks properly is a specialized work and quite expensive for small units

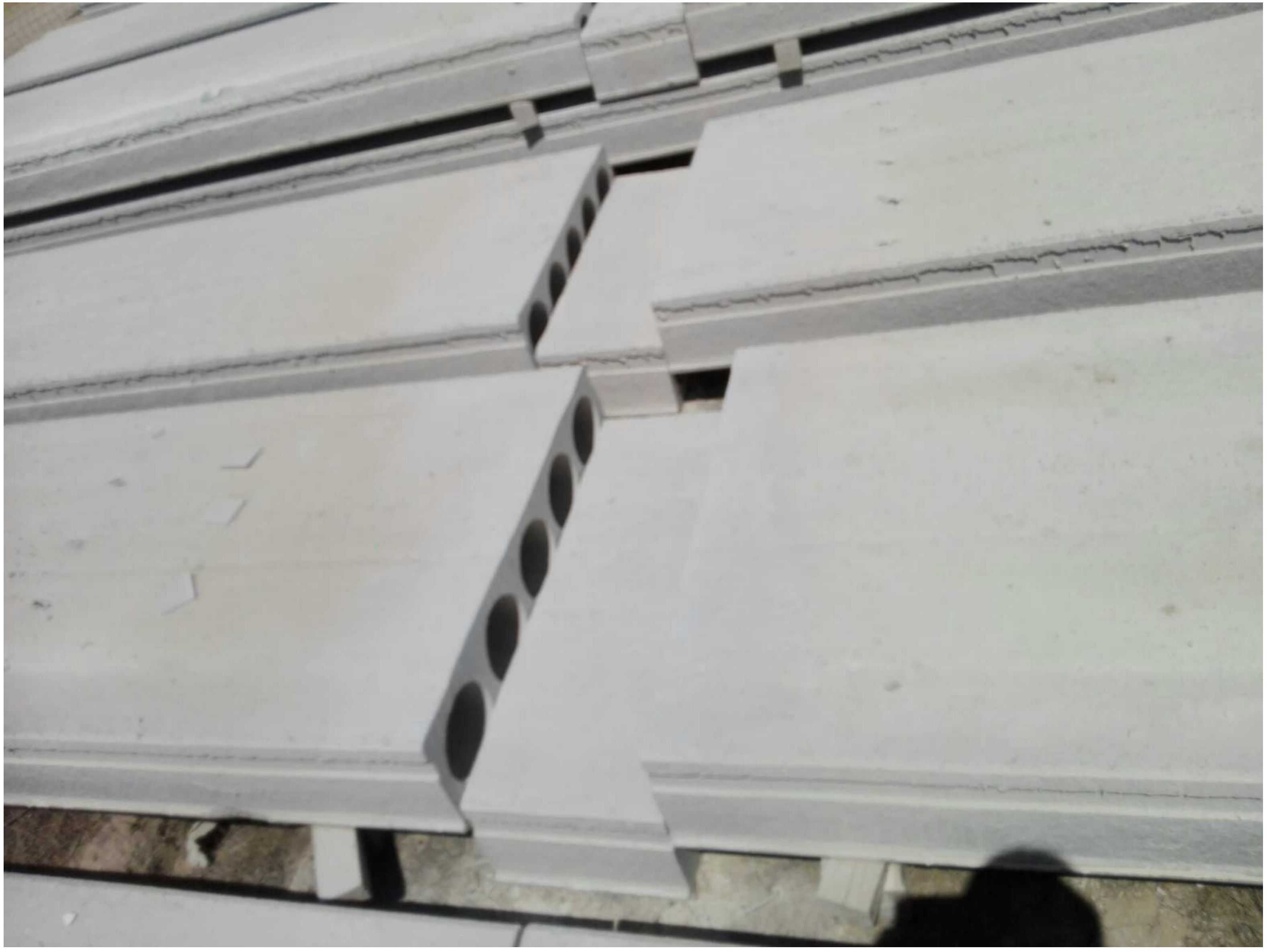
Cleaning with pressured water on site

Defect and repair in adjustment area

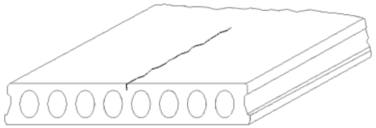


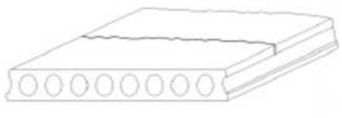
Longitudinal cutting repair

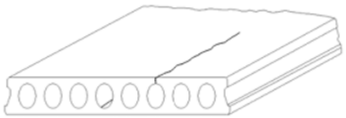
Cutting and changing the length for other uses

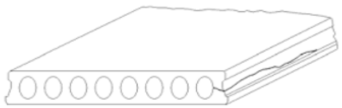


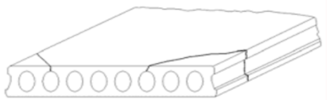
Specific cases

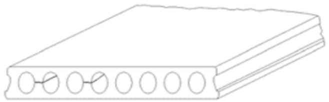
Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Longitudinal cracks at the web	**A) Improper production**			
	Subsidence over cores.	Prevent subsidence over cores.	Minor cracking should have little effect, however, it may create problems with concentrate load distribution in slabs without concrete topping.	If the crack is severe, concrete slab may be cut along its length and used as narrow width units or may be used in conjunction with a concrete topping.
	Excess water in the concrete.	Reduce water content.		
	Heat applied too early.	Delay bleeding of rubber void forms.		
	Shrinkage due to improper curing and mix proportions.	Improve curing procedures and mix.		
	Excess water in the concrete.	Reduce water content.		
	Rapid moisture loss.	Cover product as soon as possible after casting. In extreme cases spray product with mist or curing compound before covering.		
	Heat applied too early.	Increase preset time before curing temperature rise begins.		
	Excessive curing temperature.	Reduce curing temperatures.		
	Differential curing.	Check for uneven curing temperatures and make appropriate corrections.		

Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Transverse cracks	**A) Improper design**		Potential shear capacity reduction if crack occurs at end. Can have significant effect on shear and moment capacities of cantilevers. Reduction of moment inertia in centre of member can cause differential camber and excessive deflection.	For minor cracks epoxy can be effective, and filling the core solid at the crack position can enhance shear capacity. Minor cracks in the top flange at areas of positive moment may not require any repair. When a severe crack occurs in a member, the cracked section should be cut and rejected and the remaining length reclaimed and placed in the stock.
	Excessive top fibre tension.	Reduce top fibre tension.		
	Inadequate or misplaced cantilever reinforcement.	Use adequate reinforcement at proper position.		
	B) Improper production			
	Longitudinal shrinkage.	Proper mix design and curing.		
	Excessive water in concrete.	Reduce water content. Cover product as soon as possible after casting.		
	Heat applied too early.	Increase preset time before curing temperature rise begins.		
	Excessive curing temperature.	Reduce curing temperature.		
	Uneven heating along the casting bed.	Check heat distribution system.		
	Contraction due to delayed detensioning of cured product.	Detension as soon as the release strength is reached, before the product cools.		
	Low release strength	Increase release strength to accommodate top tension		
	C) Improper handling			
	Cantilever loading.	Allow adequate cantilever position.		

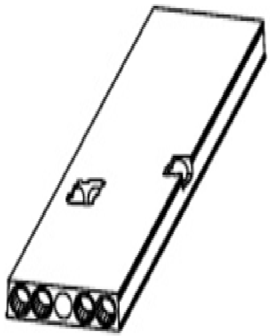
Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Longitudinal cracks over the cores	**A) Improper design**		Cracks can affect the load distribution in slabs without concrete topping. These can also have an effect on slabs with openings or transverse cantilevers.	Filling the core solid can repair these cracks. For slabs and beams used in conjunction with a concrete topping, repair may not be required. When a severe crack occurs in a member, the cracked section should be cut and rejected and the remaining length reclaimed and placed in the stock.
	Eccentricity of prestressing steel	Design with even distribution of steel.		
	B) Improper production			
	Transverse shrinkage	Proper mix design and curing.		
	Excessive water in concrete.	Reduce water content.		
	Rapid loss of moisture.	Cover product as soon as possible after casting. In extreme cases spray product with mist or curing compound before covering.		
	Heat applied too early.	Increase preset time before curing temperature rise begins.		
	Excessive curing temperature.	Reduce curing temperature.		
	Different curing temperatures at each side.	Check for uneven curing temperatures and make appropiate corrections.		
	Diferencial compaction.	Improve vibration.		
	Steel displaced during casting.	Prevent displacement of steel.		
	Improper cutting sequence.	Cut steel from centre to outside.		
	Flange too thin due to movement or misalignment of voids.	Correct and maintain core positions.		
	Over-inflation of void formers.	Maintain proper inflation.		
	C) Improper handling and storage			
	Handling problems.	Use appropiate method of handling.		
	Uneven stacking.	Provide uniform bearing.		
	Settlement of the stack.	Put heavier product at bottom of stack and reduce stack height.		

Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Longitudinal web cracks at or near the strand	**A) Improper design**		These cracks can reduce the shear capacity because effective and undamaged webs resist the shear stress. Evaluate a shear capacity reduction similar to members with openings near the end.	The repair of these cracks is dependent on the shear requirements. The cores can be filled solid. When a severe crack occurs in a member, the cracked section should be cut and rejected and the remaining length reclaimed and placed in the stock.
	Excessive bursting stresses.	Reduce bursting stresses.		
	Web not thick enough for the prestress force.	Increase web thickness if possible.		
	Strand diameter too large for thin web	Provide equivalent prestress with smaller diameter strand.		
	B) Improper production			
	Lateral strand movement during casting.	Check strand guides on casting machine.		
	Low release strength.	Increase release strength.		
	Lack of concrete compaction around the strands.	Improve concrete compaction.		
	Layers of concrete not bonded.	Revise production procedures to avoid cold joints.		
	Saw-cut not deep enough or not complete across the sides.	Saw completely through the section of the member.		
	C) Improper handling			
	Uneven handling due to picking devices not being level.	Use spreader beams to minimise uneven handling.		

Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Cracks at corner of the member 	**A) Improper production** Saw blade pinches when member cambers. Saw cut not deep enough or wobbles due to excessive use. Excessive tension stress during stripping. **B) Improper handling and storage** Uneven stacking. Uneven handling to due picking devices not being level. Damage during transport.	Place weight on member to restrict camber. Cut completely through the strands and as close as possible to the bottom of the member and use a properly maintained saw, Employ proper cutting sequence. Provide level bearing in the stack. Use spreader beams to minimise uneven handling. Ensure good transport procedures are adhered to.	The effect of these cracks is usually minimal but can reduce the shear capacity if the webs are damaged. Evaluate a shear capacity reduction similar to members with openings near the end. If the damage is severe, cut and reject the end of the member and use the remaining of the length.	The repair of these cracks is dependent on the shear requirements. Epoxy resin can be used and the cores can be filled solid. When a severe crack occurs in a member, the cracked section should be cut and rejected and the remaining length reclaimed and placed in the stock.

Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Cracks in the web above the strand	**A) Improper design**		These cracks can reduce the shear capacity because effective and undamaged webs resist the shear stress. The design shear capacity should be reduced and conservative to make allowance for the damaged webs.	The shear capacity may be enhanced by filling solid cores where the webs are damaged.
	Excessive prestress force in relation to the cross sectional area of concrete.	Reduce shear lag through webs. Increase web width. Add top strand. Reinforce webs Reduce prestress force.		
	B) Improper production			
	Insufficient release strength,	Increase release strength.		
	Bottom surface of member sticking to the bed during striping.	Clean and oil casting bed properly or ensure a dry contact surface.		
	Saw cut not deep enough.	Cut completely through the strands and as close as possible to the bottom of the member.		
	Mix too wet or too dry.	Adjust the mix accordingly.		
	Insufficient vibration.	Improve vibration and compaction.		

Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Accidental cracks	**A) Improper handling and storage**		Depending on their location and severity, these cracks can have significant effect on the slabs capacity. Evaluate the severity of the damage on the bending and/or the shear capacity. Work out the residual capacity of the damaged slab prior to repairs ad check to see if this is adequate. If the residual capacity is adequate proceed with the repairs, if not either reject the member or cut and reject the damaged area.	If large pieces of concrete have been removed these can be replaced with fresh and well compacted concrete, provided the slab is adequate without the repair. Cracks can be repaired with Epoxy resin or concrete mortar. Where a severe damage occurs in a localised area of a member, the damaged area should be cut and rejected and the remaining length reclaimed and placed in the stock.
	Transport over uneven ground.	Transport product over a well defined even ground.		
	Product transported at high speed.	Transport product at reasonable speed.		
	Improper transport machinery.	Use only appropriate machinery for transporting the product.		
	Lack of training.	Train the personnel involved in transporting and stacking the product.		
	Stacking in uneven ground.	Stack product only on even ground.		
	Misplaced bearers.	Bearers should be placed at the right places and should be of the right size and shape.		
	Products with different sizes and shapes.	Each stack should only have products with similar size. Do not exceed the maximum number of rows permitted.		

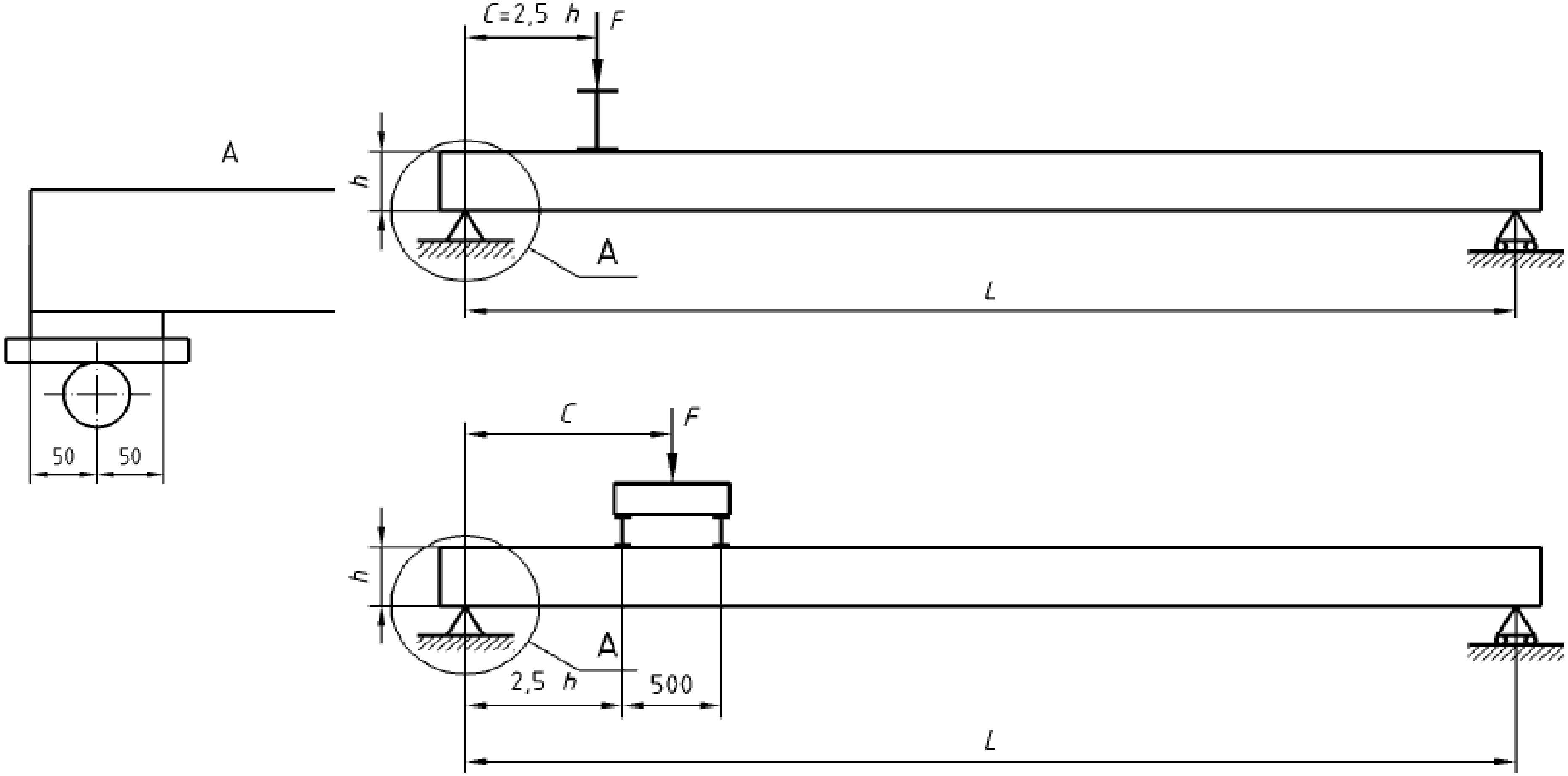
Typical case (hollow cores)	Cause	Prevention	Effect	Repair
Imperfections in holes, recesses or lifting devices	**A) Improper design or production**			
	Lack of dug holes or recesses	Improved data transfer at stage of design and manufacture and improved quality control of production	Joints cannot be finished and installations of piping cannot be done.	Recess shall be made carefully on site. Small holes are drilled and big holes cut on site.
	Lack of lifting hooks.		Lifting difficult or dangerous.	Lifting are made with special equipment.
	Lack of intermediate webs or other strengthening for lifting.			Lifting are made with special equipment.
	Lack of drilled water holes in lower flange.		Rainwater can gather into the cores during construction.	Water holes are drilled on site.
	Lack of plugs or other filling material for core ends.		Additional use of joint cast. Deadweight of slabs increases.	Cores are plugged or ends filled with other methods before joint cast.

5. Full scale loading tests

- For product family, at the beginning of production as acceptance test. At least three units
- During production as quality control test:
  - Every 3-6 months
  - Per type of slab each 25,000-50,000 m^2
- Shear test
- Flexural test
- Loading procedure
  - First cycle: 35% expected failure F_{cal}
  - Second cycle: 50% F_{cal}, 75% F_{cal}, and up to failure
- Initial type testing:
  - $F_{test} / F_{cal} \geqslant 0.95$ for each test
  - $F_{test} / F_{cal} \geqslant 1.00$ average value of three tests

Flexural test. No need to break the unit, once the maximum load is reached and the deflection increases without increasing the load.
Possible problems with the jack

Shear test. Length of the slab at least 4.0 m or 12 h



Shear test

Thank you for your attention