IRISH CONCRETE SOCIETY

National 3rd Level Concrete Technology Course

TRINITY COLLEGE DUBLIN
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Course Contents

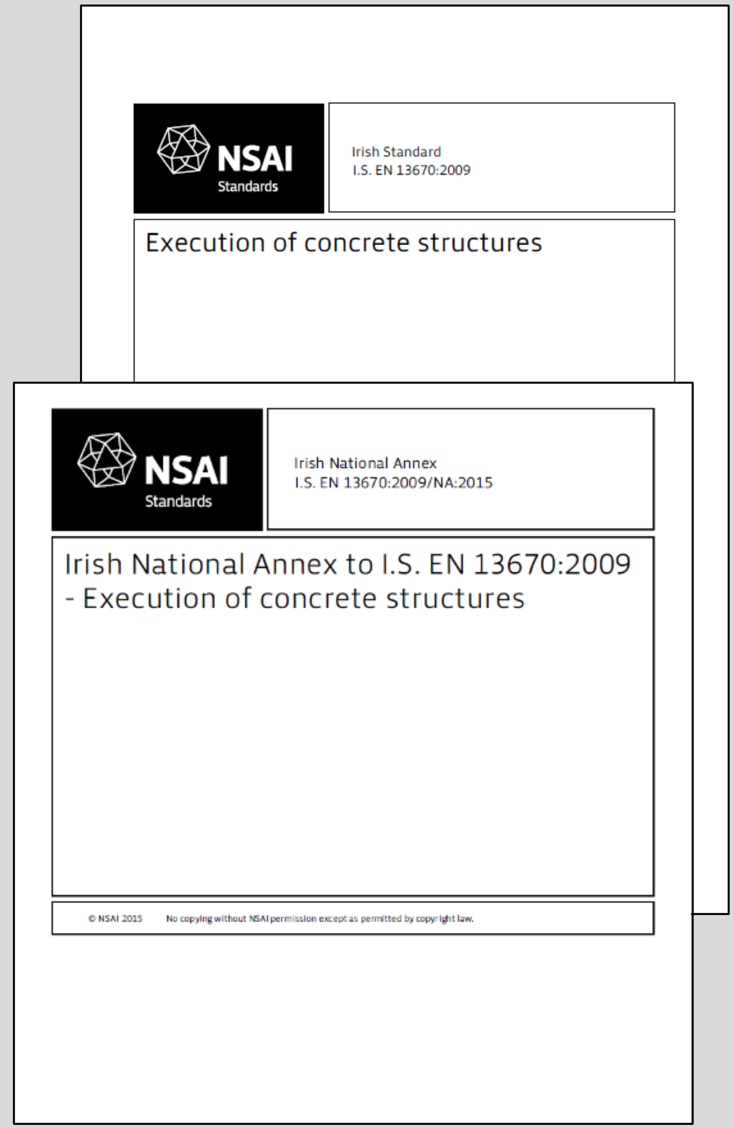
1. Introduction
2. Constituents, Mix Design & Production
3. Hydration & Curing
4. Fresh & Hardened Properties, Testing
5. Specification, Durability Design
6. **Site Activities, Reinforcement & Formwork**
7. Special Concretes & Structures

6. Site Activities, Reinforcement & Formwork

1. Introduction
2. Execution Standards (IS EN13670)
3. Falsework & Formwork
4. Reinforcement
5. Prestressing
6. Concreting
    - 6.1 Specification
    - 6.2 Placing & Compaction
    - 6.3 Curing &Protection
    - 6.4 Finishes

2. Execution Standards

- All work must conform to internationally accepted standard
- I.S. EN 13670
- Irish National Annex to EN13670


NSAI Standards

Irish Standard
I.S. EN 13670:2009

Execution of concrete structures

NSAI Standards

Irish National Annex
I.S. EN 13670:2009/NA:2015

Irish National Annex to I.S. EN 13670:2009
- Execution of concrete structures

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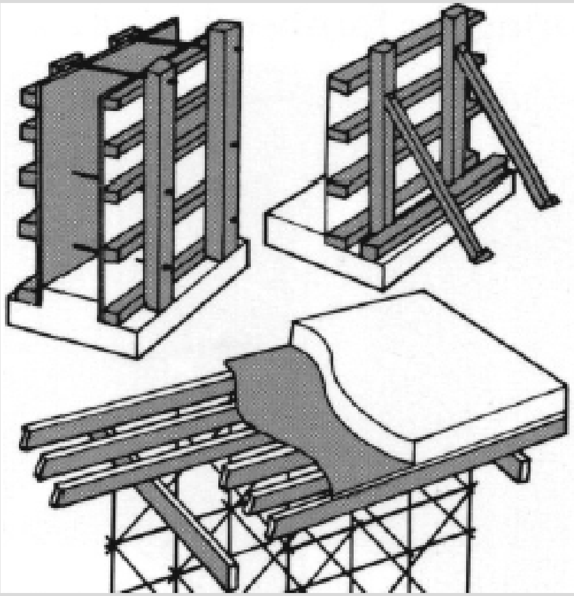
3. Falsework & Formwork

- **Formwork** – the “jelly mould” which holds the liquid/fresh concrete in the desired shape

- **Falsework** – the support structure which holds the formwork in place

3.1 Formwork - Requirements

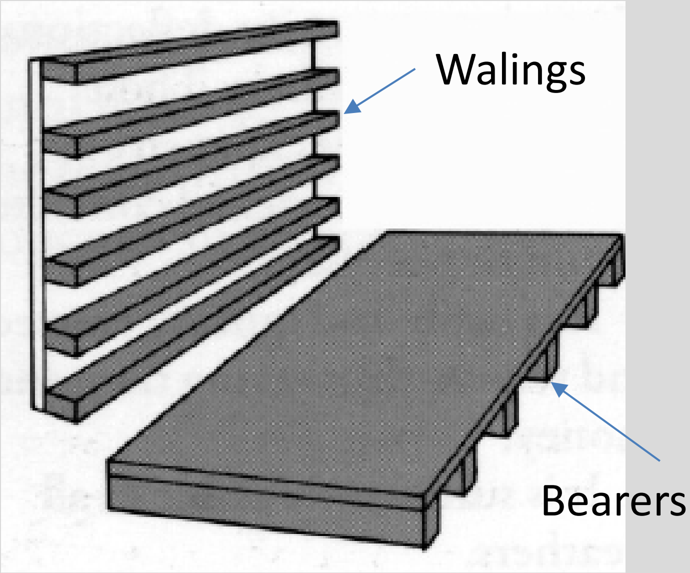
- Must ensure concrete is poured to required shape, size and position
- Must provide required surface finish to concrete
- Must be securely fixed
- Must be possible to strike formwork cleanly and easily without damaging the concrete surface



3.2 Formwork - Materials

- Timber
- Aluminium
- Steel
- Plywood
- Plastics
- Other

3.2.1 Timber Formwork



Traditional Timber Formwork

- Most common
- Traditional material
- Easily cut and assembled on site
- Used in both vertical and horizontal forms
- Timber graded into classes based on strength – essential to use correct grade

3.2.2 Aluminium Formwork

- Smaller joists and proprietary beams.
- Strong and light, often need fewer supports and ties than timber.
- Care needed to avoid deflection issues.

3.2.3 Steel Formwork

- Both proprietary and purpose-made.
- Proprietary systems usually consist of panels with steel frames and either plywood or steel cladding.
- A range of adjustable props, soldiers, light walings and ties available.
- Purpose-made often used when dimensional tolerances are critical.
- Steel formwork particularly economical when re-usable.
- Avoids loss of moisture from concrete.
- Provides excellent surface finish.

3.2.4 Plywood

- Used as cladding in either timber, steel or aluminium frames.
- Water absorption from concrete can cause problems.
- Often lined or coated with waterproof liners.

3.2.5 Plastic Formwork

- Glass-Fibre Reinforced Polymers (GRP's) offer advantages ofver more traditional materials.
- Used when complicated shapes or surface featueres to be cast many times.
- Care needed with release agent (see later)
- Care needed when vibrating concrete not to scour the surface of the grp formwork.
- Particularly useful on waffle and voided slabs.

3.2.6 Other Formwork Materials

- Cardboard
- Expanded Polystyrene
- Expanded Metal

3.3 Release Agents

- Used so concrete does not adhere to formwork face
- Applied before concreting starts and before reinforcement is fixed
- Release agent depends on material of formwork
- Follow manufacturer’s instructions and dosages
- Too much can cause staining on concrete surface
- Wipe off excess with a cloth

3.4 Design of Formwork & Falsework

- Both formwork and falsework need to be designed (normally as temporary structures) to resist the loads applied by the concrete in its plastic state.

- 4 main areas for formwork:
  - Walls
  - Columns
  - Beams
  - Slabs

3.4.1 Wall Formwork

- Double-faced (held together by tie rods)

- Single-faced (e.g. edges to small bases)

3.4.2 Soffit Formwork

- Underside of suspended slabs and beams known as soffit formwork)
- Needs to be able to carry all applied loads e.g. fresh concrete, construction equipment, weather imposed loads, etc.
- Generally supported by steel or aluminium props

3.4.3 Formwork – Design Considerations

a) Self-weight of formwork, reinforcement and concrete;

b) pressure on formwork (including possible uplift);

c) construction loads (crew, equipment, etc.), including static and dynamic effects of placing, compacting and construction traffic;

d) wind and snow loads;

e) particular actions at the place of execution such as provision for seismic actions.

3.4.3 Formwork – Design Considerations

- Before concrete hardens, it acts like a liquid and pushes against the forms the way water presses against the walls of a storage tank.
- **Lateral Liquid Pressure:**

$$P = \rho \times g \times H$$

Where:

P = Lateral Pressure

ρ = Density of liquid

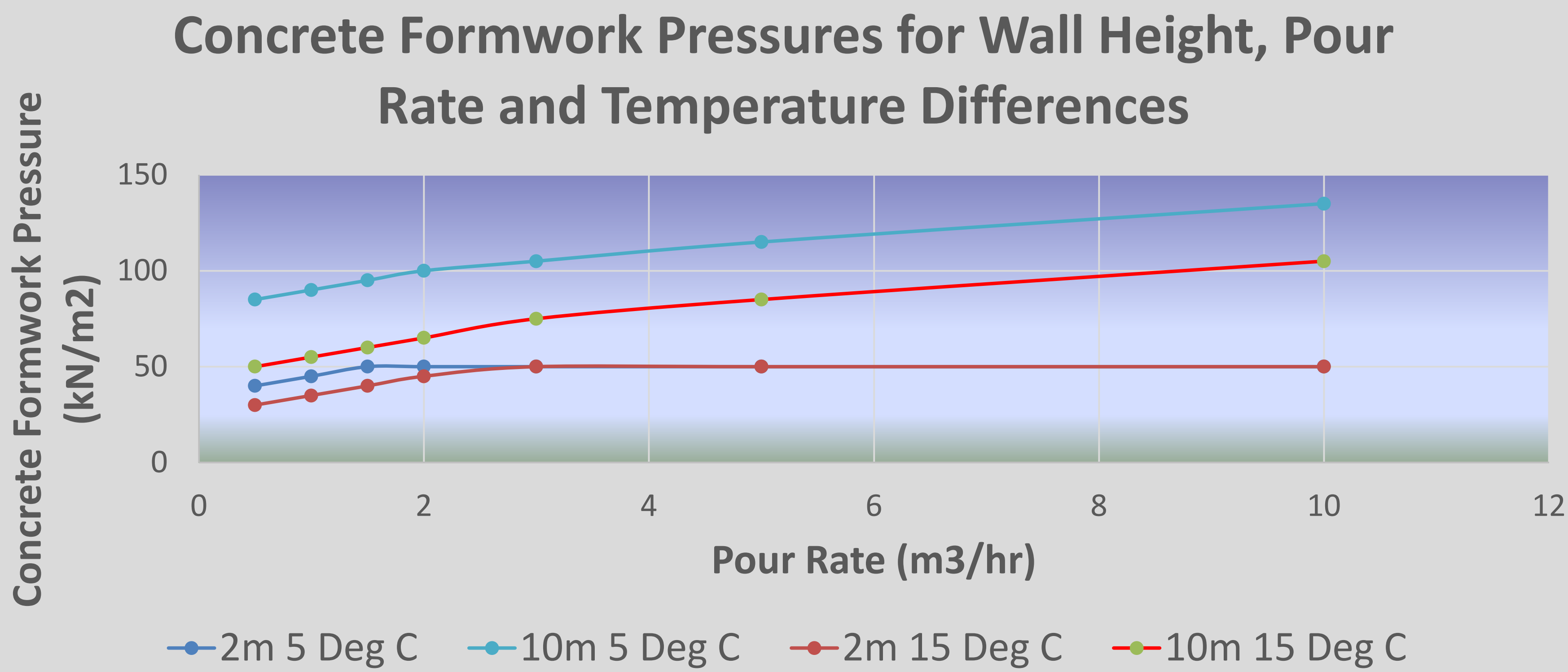
g = Acceleration due to Gravity

H = Height of liquid head

3.4.3 Formwork – Design Considerations

- **Lateral concrete pressure** on formwork is affected by:
  - Height of concrete pour (H)
  - Concrete pour rate (H)
  - Weight of concrete (ρ)
  - Temperature (H)
  - Type of cement (H)
  - Vibration (H)
  - Concrete slump (water–cement ratio) (H)
  - Chemical additives (H)

3.4.4 Effect of Pour Rate, Temperature and Wall Height on Concrete Formwork Pressure



3.5 Installation of Formwork

- Use all panels in correct positions.
- Make sure all accessories are right size and correct spacing.
- Check falsework is securely braced.
- Ensure all inserts and boxes are securely fixed and easily removable.
- Remove any tie-wire clippings, nails and debris.
- Ensure access for concreting gang.
- Ensure all props are in good condition and erected correctly.
- Apply release agent (in accordance with manufacturer's instructions.

3.6 Concreting

- See Section 6.

3.7 Removal of Formwork

- Formwork can be removed or “struck” once the concrete has gained enough strength to be self-supporting (including any applied loads during the early stages)
- Minimum strength requirement of $5N/mm^2$ (IS EN13670)
- Longer times needed if retarder or high PFA/GGBS content
- No stripping if temperature less than 5^oC due to frost risk
- Precast manufacturers use active thermal curing to strip within 24 hours

3.7.1 Formwork Striking Times – in situ

Strength Development: Typical Minimum Formwork Stripping Times

	Hot (> 20°C)	Average (12 - 20°C)	Cold (5 - 12°C)
Vertical	1 day	2 days	3 days
Beams and slab soffits	4 days	6 days	8 days
Backprops	12 days	18 days	24 days

3.7.3 Formwork Removal Process

- Ensure space allocated for cleaning forms upon removal
- Loosen ties and clamps gradually
- Leave blocking out pieces as long as possible
- Large sections to be removed by crane.

3.7.3 Formwork Removal Process

- Handle removed sections carefully
- Once formwork is struck, curing should start immediately to prevent excessive loss of moisture from concrete surface.

3.7.4 Formwork Cleaning & Storage

- Forms should be cleaned as soon as possible
- If not to be used for a long time they can be oiled (steel) or coated with a release agent (timber) to prevent deterioration
- Place into storage immediately after cleaning (and treating)

4. Reinforcement - Introduction

- Purpose
- Reinforcement types and properties
- Reinforcement drawings and schedules
- Fixing
- Site storage
- Quality control

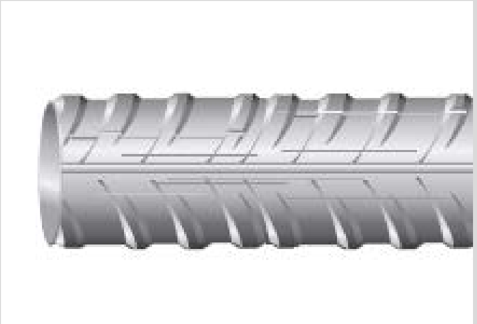
4.1 Reinforcement - Purpose

- Primarily to add tensile strength to concrete

- Also used to control/limit crack formation and development

4.2 Reinforcement Types & Properties

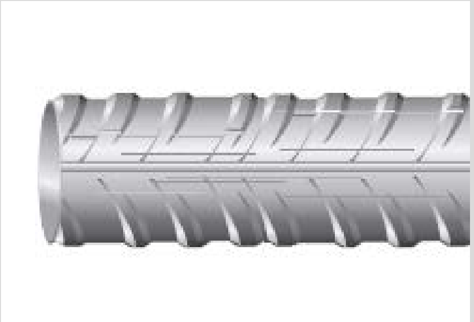
- Most common material is steel (high yield, mild, galvanised, etc. depending on the application)

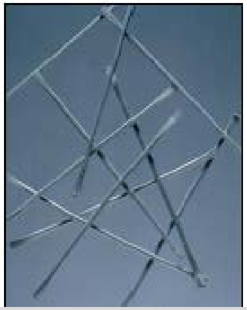


- Other materials such as fibre reinforced polymer (FRP) composites gaining popularity due to non-corrosive nature, high strength to weight ratios, non-magnetic.

- Typical fibres in FRP materials include carbon (CFRP), aramid (AFRP), glass (GFRP) and basalt (BFRP)

4.3 Reinforcement Forms





Synthetic fibres

close –up of synthetic fibres

Steel fibres

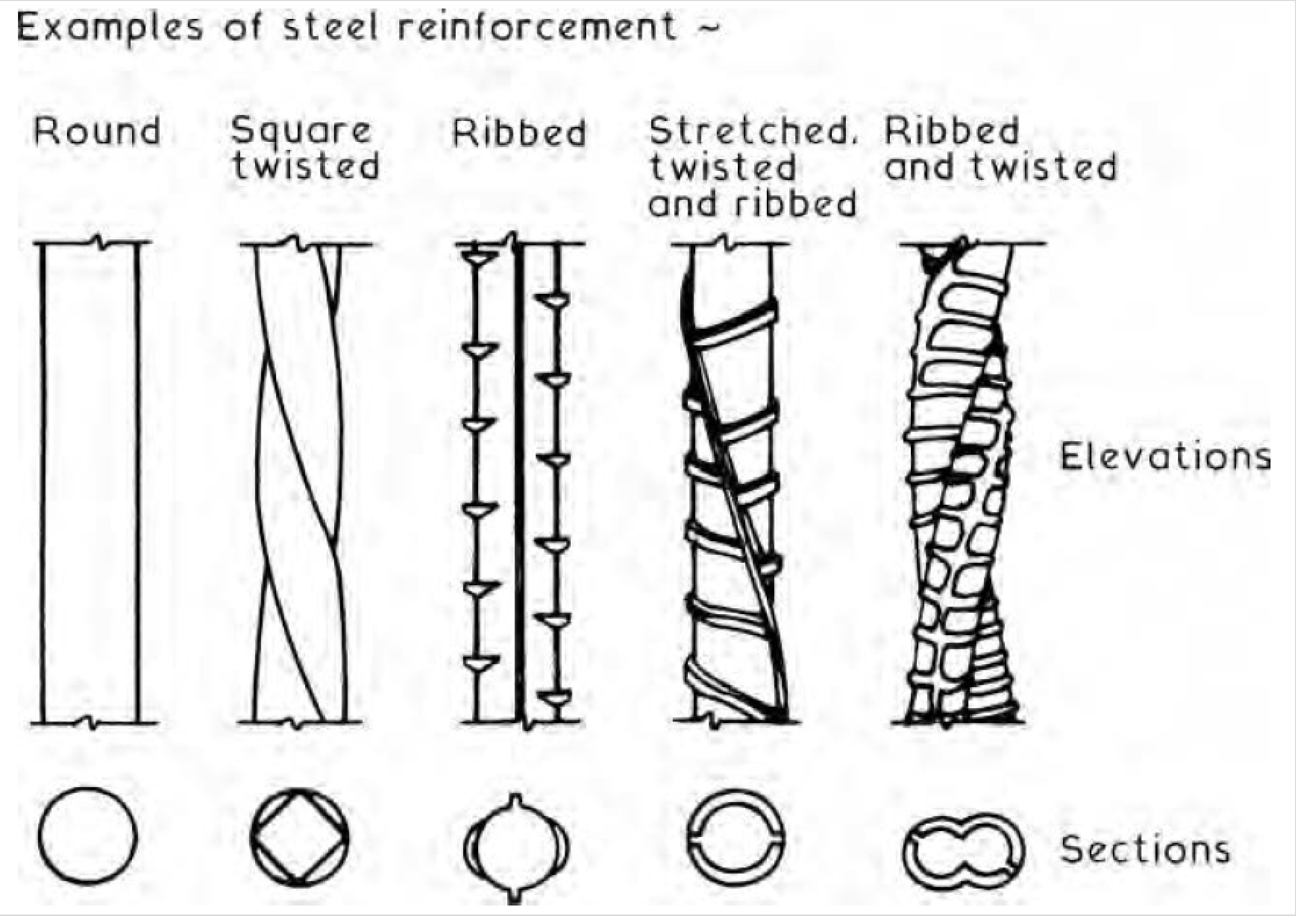
Fibres

4.4 Reinforcement Properties

Property	Steel Rebar	Steel Tendon	GFRP Rebar	CFRP Tendon	AFRP Tendon
Tensile Strength (MPa)	4811.690	1379-1862	517-1207	1200-2410	**1200-2068**
Yield Strength (MPa)	276-414	1034-1396	N/A	N/A	**N/A**
Tensile Elastic Modulus (GPa)	200	186-200	30-55	147-165	**50-74**
Ultimate Elongation (%)	>10	>4	10.4.5	10.1.5	**10.2.6**
Compressive Strength (MPa)	276-414	N/A	310-482	N/A	**N/A**
Coefficient of Thermal Expansion (10^{-6}/˚C)	11.7	11.7	9.9	0	**-10.-0.5**
Specific Gravity	**7.9**	**7.9**	**1.5-2.0**	**1.5-1.6**	**1.25**

¥ The properties given are circa 2000.

4.5 Steel Reinforcement - Types



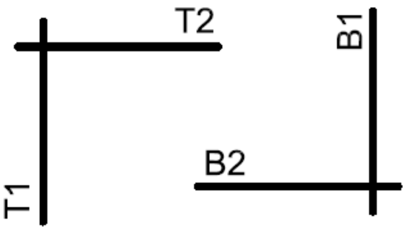
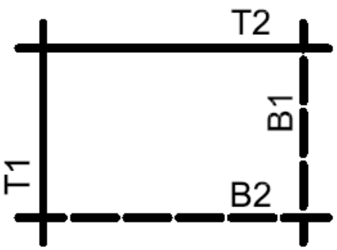
4.5.1 Steel Reinforcement - Drawings

- EN ISO 3766 provides system of representing bars on drawings and documentation

Table 1 — Representation and drawing conventions of concrete reinforcements without prestressing

No.	Description	Representation
1	**Views**	
	a) General representation of bar by a continuous extra-wide line	
	b) Bent reinforcement bar	
	1) representation as a polygonal continuous line or	
	2) representation as a continuous line made up of straight lines and arcs	
	c) Bundle of bars drawn using a single line, with end markings indicating number of bars in bundle	
	EXAMPLE Bundle of three identical bars.	
2	**Section of bar**	
	a) section of single reinforcement bar	
	b) bundle of two reinforcement bars	
	c) bundle of three reinforcement bars	

4.5.1 Steel Reinforcement - Drawings

16	**Location of layers of reinforcement on plan drawings** where B is the bottom layer; T is the top layer; 1 is the layer nearest the concrete face; 2 is the second layer from the concrete face. NOTE B and T are used for the English language; equivalent letters for other languages are possible.	
	a) bottom and top layers shown on separate plans	
	b) bottom and top layers shown on the same plan (The bottom layer shall be indicated by a dashed extra-wide line.)	

4.5.1 Steel Reinforcement - Drawings

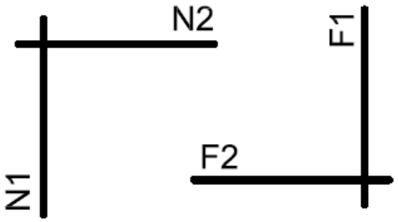
17 **Location of layers of reinforcement on elevation drawings**

where

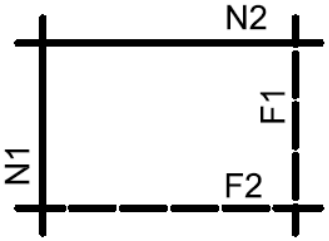
- N is the near face
- F is the far face
- 1 is the layer nearest the concrete face
- 2 is the second layer from the concrete face

NOTE N and F are used for the English language; equivalent letters for other languages are possible.

a) near-face and far-face reinforcement shown on separate elevations



b) near-face and far-face reinforcement shown on the same elevation (The far face layer shall be indicated by a dashed extra-wide line.)

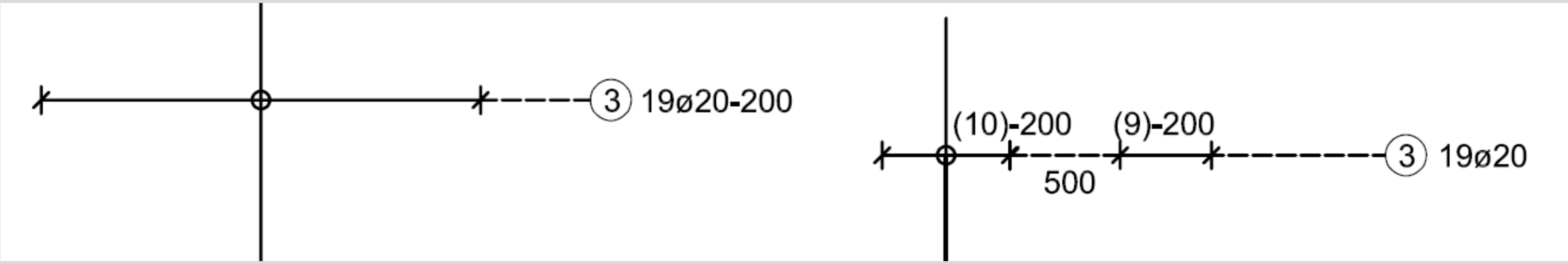


4.5.2 Steel Reinforcement – Bar Marks

Table 3

Indication	Example
Alphanumerical bar mark (surrounded by, for example, a circle or an oval)	③[a]
Number of bars	19
Bar diameter, in millimetres	Ø20
Spacing, in millimetres	200
Position in the component or construction part (optional)	T
Shape code of reinforcement bar (optional)	13

[a] Indication for the example: ③ 19 Ø20—200—T—13 or ③ 19 Ø20—200. See Figure 1.



4.5.3 Steel Reinforcement - Coding

- Based on 2 characters
- 1st Character
  - No. of arcs or bends or type of bends
- 2nd Character
  - Bending direction

Table 4 — Shape code composition

First character			Second character	
0	No bends (optional)		0	Straight bars (optional)
1	1 bend		1	90° bend(s) of standard radius, all bent towards the same direction
2	2 bends		2	90° bend(s) of non-standard radius, all bent towards the same direction
3	3 bends		3	180° bend(s) of non-standard radius, all bent towards the same direction
4	4 bends		4	90° bend(s) of standard radius, not all bent towards the same direction
5	5 bends		5	Bends < 90° of standard radius, all bent towards the same direction
6	Arcs of circles		6	Bends < 90° of standard radius, not all bent towards the same direction
7	Complete helices		7	Arcs or helices
9[a]	Can only be combined with character 9		9[a]	Can only be combined with character 9

NOTE 1 This table explains the logic behind the numbering of the shapes in Table 5.

NOTE 2 The number of bends does not include bends for hooks as stated below.

[a] 99 Special non-standard shapes defined by a sketch. Shape code 99 shall be used for all non-standard shapes. Bending radii for shape code 99 shall be assumed to be standard, unless otherwise specified.

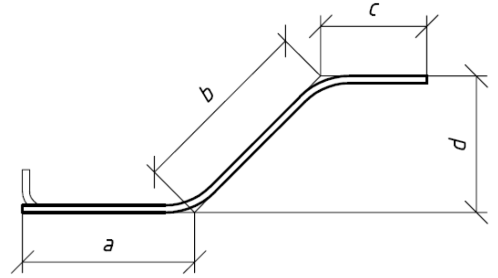


Figure 2 — Bending dimensions — Shape code 26

4.5.6 Steel Reinforcement – Bar Schedule

- Used to specify and identify reinforcing bars.

Table 6 — Example for shape schedule without title block

Member	Bar mark	Type of steel	Bar diameter mm	Length of each bar (Method A) m	Number of members	Number of bars in each member	Total number	Total length m	Shape code	End hook		Bending dimensions mm							Index
												a	*b*	*c*	*d*	*e*	*R*	*h*	
Slab 1	01	BST 500 S	28	3,60	1	10	10	36,00	00	0	0	3 600							
Slab 2	02	BST 500 S	28	3,94	1	20	20	78,80	11	1	1	2 400	1 000					270	
Slab 3	03	BST 500 S	28	3,17	1	2	2	6,34	12	1	1	1 520	1 320				472	270	
Corbel	04	BST 500 S	16	3,27	5	3	15	49,05	13	1	1	1 320	640	1 320				130	
Wall	05	BST 500 S	28	6,34	2	4	8	50,72	15	1	1	1 000	4 800	1 500				270	
Beam 1	06	BST 500 S	16	2,16	4	14	56	120,96	21	−1	−1	800	300	800				130	
Beam 2	07	BST 500 S	20	3,32	3	21	63	209,16	25	2	2	800	1 000	800	740	775		360	
Beam 3	08	BST 500 S	28	3,14	3	6	18	56,52	26	1	1	700	700	1 200	500			270	
Beam 4	09	BST 500 S	12	2,40	1	13	13	31,20	31	1	1	800	550	400	450			100	
Beam 5	10	BST 500 S	10	3,24	1	26	26	84,24	41	1	1	1 280	700	500	300	300		80	
Foundation slab 1	11	BST 500 S	12	1,80	2	300	600	1 080,00	44	1	1	200	450	300	450	200		100	
Foundation slab 1	12	BST 500 S	28	4,96	2	12	24	119,04	46	1	1	1 000	710	800	500	1 200		270	

4.6 Storage & Placement

- Bars must be stored clean, off the ground and away from oil and mud.
- Cutting and bending of bars on site should be avoided where possible.
- Proper, accurate placement of reinforcement is essential.
- Spacers and chairs can achieve proper placement and ensure uniform depth of cover.

Spacers

Chairs

5. Prestressing

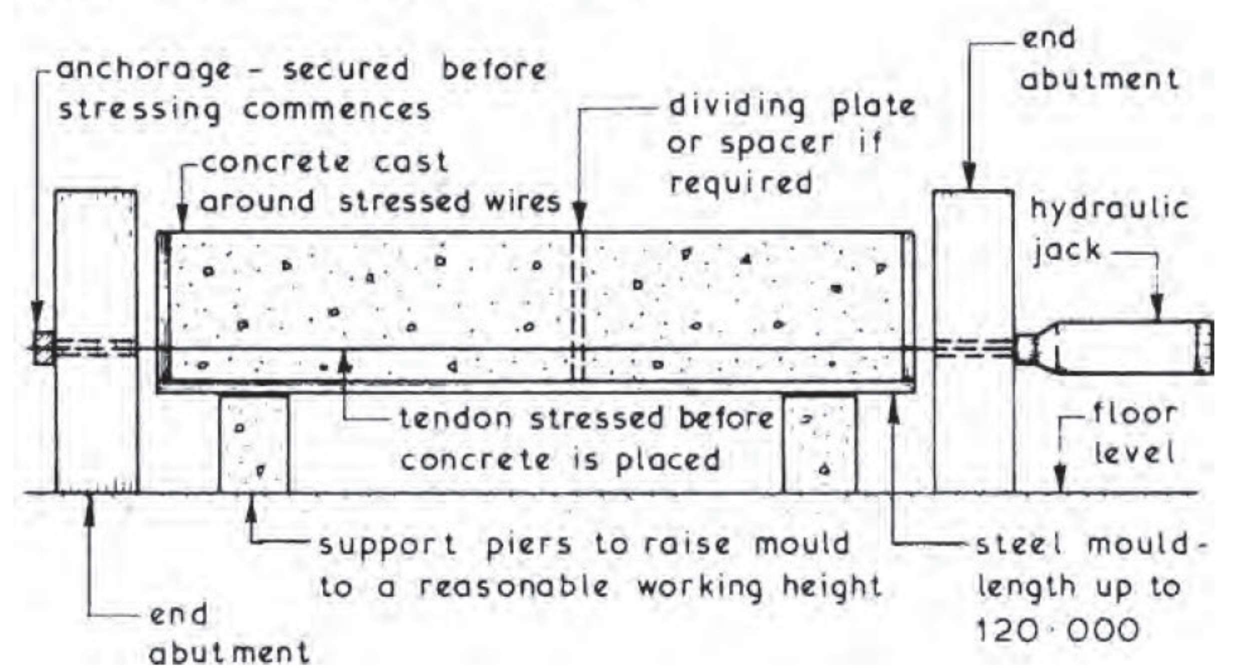
- Idea is to make best use of material properties of steel and concrete by preloading to induce early compressive stress in concrete

- Can be achieved by **pre-tensioning** or **post-tensioning**

- Reinforcement in the form of **strands**

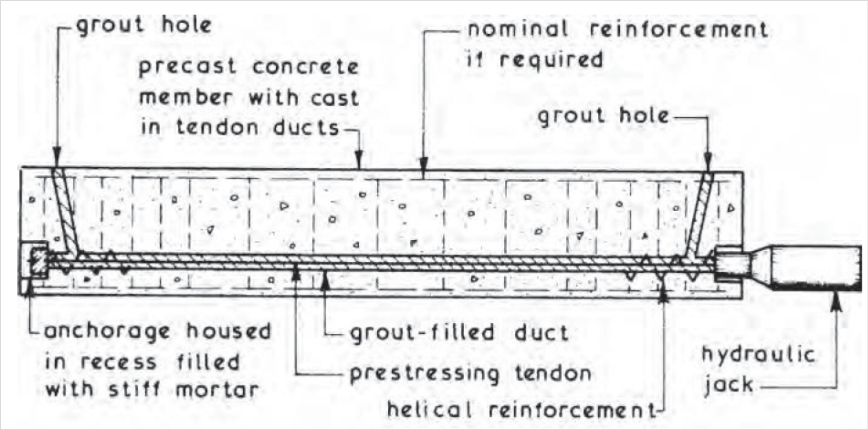
5.1 Pre-tensioning

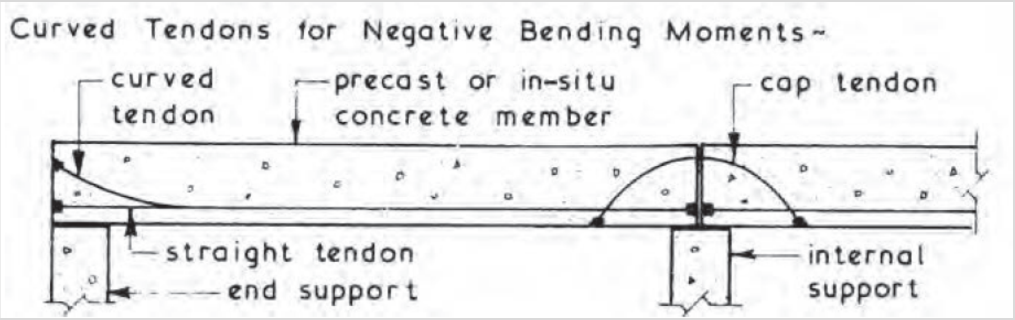
- Generally used for precast members (factory setting)
- Wires/strands in tension prior to concrete hardening
- After curing, wires are released, transfer to concrete occurs



5.2 Post-tensioning

- Usually carried out on-site
- Also used for curved tendons to overcome negative bending moments
- Concrete cast around ducts or sheaths which will house tendons
- Stressing is carried out after the concrete has cured
- Anchorages prevent tendon from regaining its original length and transfer force to concrete

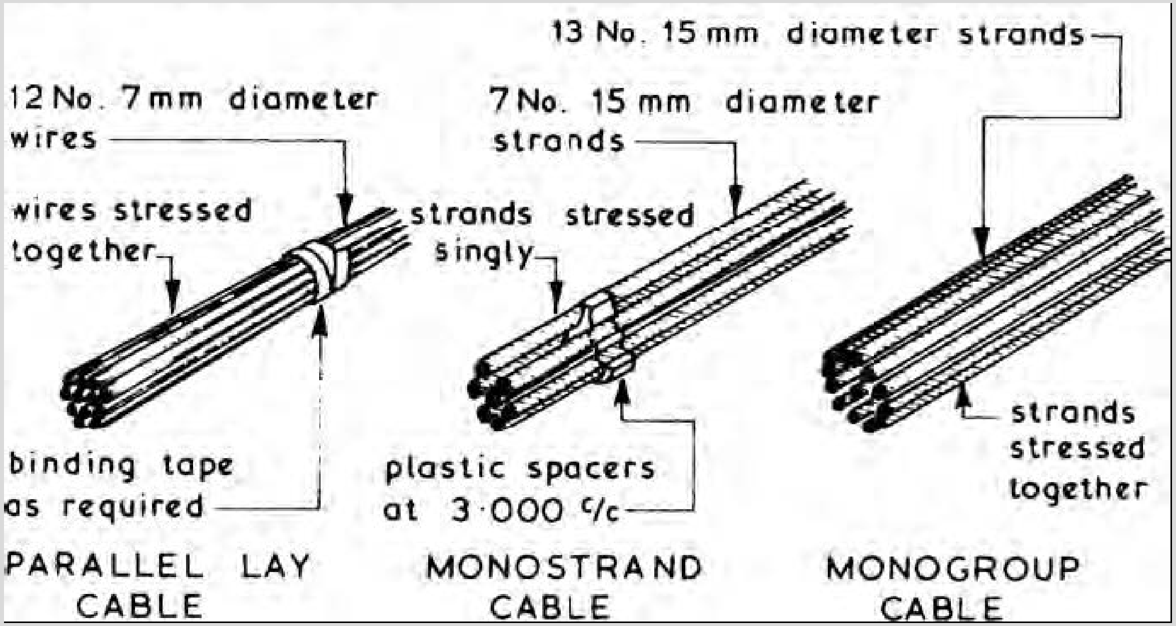




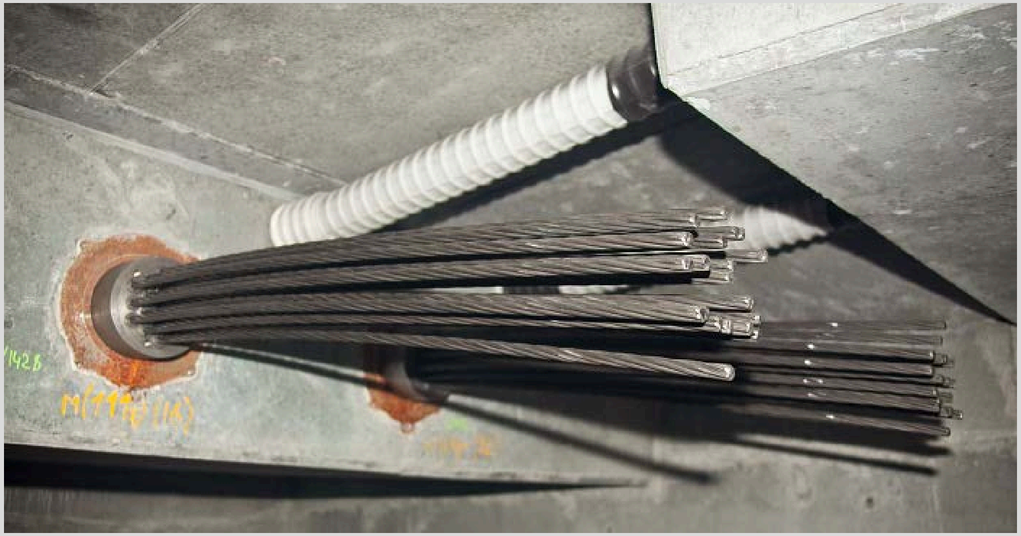
5.3 Tendons & Strands

Tendons

7-wire Strands



5.4 Anchorage



5.5 Hydraulic Jack

Hydraulic Pump

Hydraulic Jack

6. Concreting

- Handling & Placing Concrete
- Compaction
- Finishes
- Joints

6.1 Handling & Placing Concrete

- Directly into element

- Transport by :
  - Dumper
  - Crane & Skip
  - Pumped

6.1.1 Handling & Placing concrete – Crane & Skip

Directly into element
Transport by:

- Dumper
- **Crane & skip**
- Pumped

6.1.2 Handling & Placing Concrete - Pumping

Directly into element

Transport by:

Dumper

Crane & skip

Pumping

6.1.2 Handling & Placing concrete – Pumping

Directly into element

Transport by:

Dumper

Crane & skip

Pumping

6.2 Placing concrete

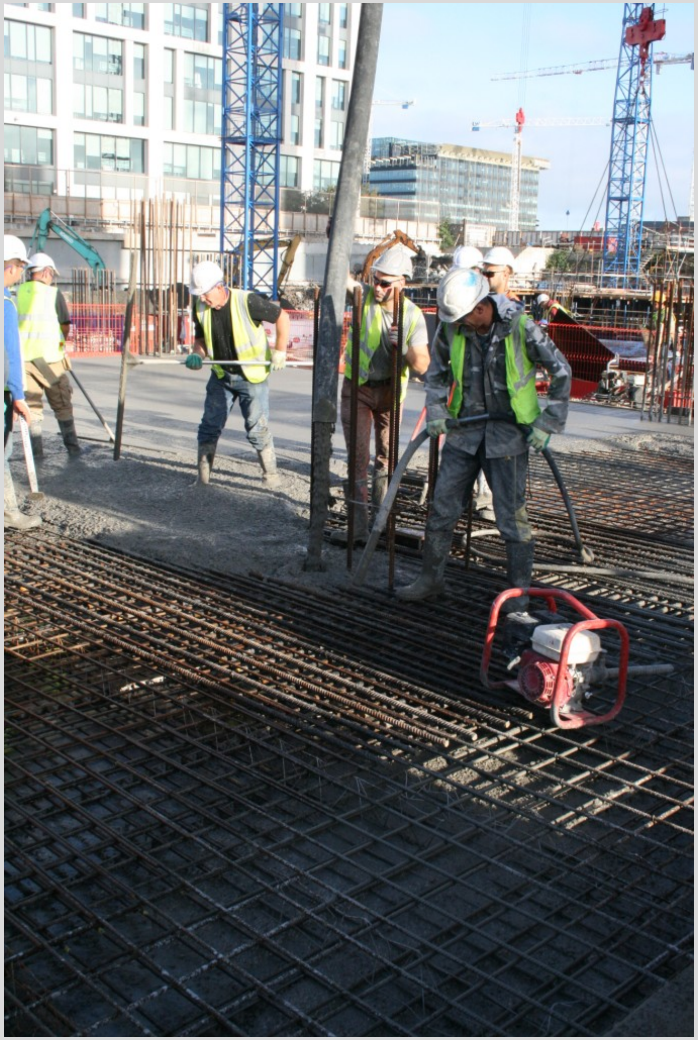
- Pre-concreting checks
- Deposit as close to its final position as possible
- Placing rate – controlled
- Continuity of placing

6.3 Compaction

Why is compaction necessary ?

To achieve full density

- **Strength**
- **Durability**
- **Bond**
- **Finish**

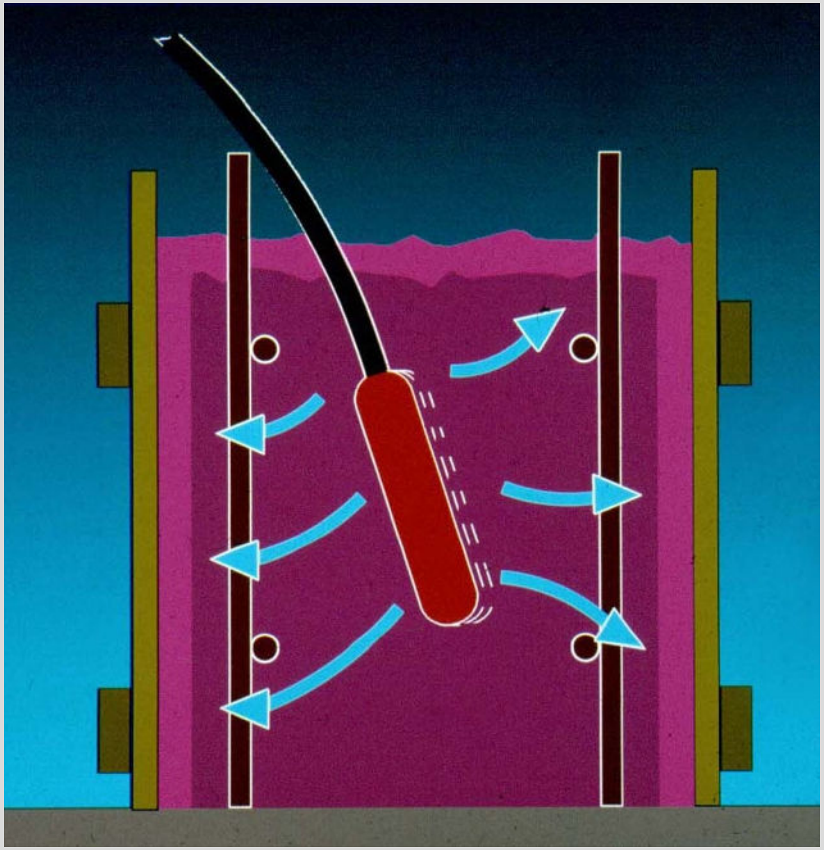


6.3 Compaction Process

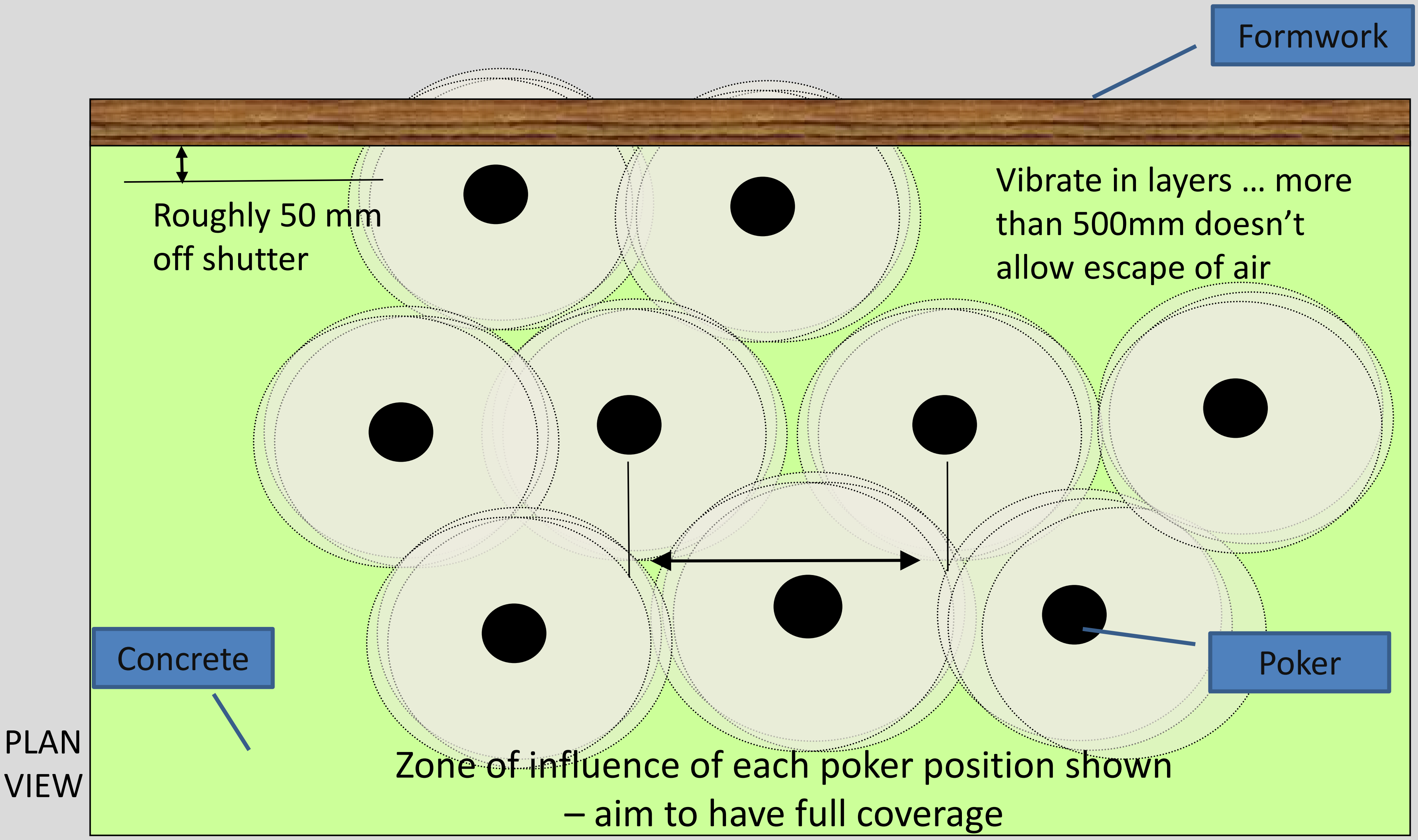
- Place in layers
  - < 500 mm

- Compact
  - To remove entrapped air

- Different methods of compaction:
  - Poker vibration
  - Beam vibrators



6.3.1 Poker Vibration -Radius of Action/Effect



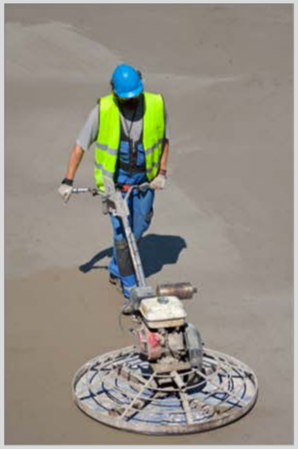
6.4 Finishes - Unformed

- I.S. EN 13670 descriptions

- Unformed Finishes
  - **Basic** ; Closed uniform surface
  - **Ordinary** ; Surface produced by floating
  - **Plain** ; Dense smooth surface (trowelling)
  - **Special**

6.4 Finishes - Unformed

- Power-trowelled
  - Dense smooth surface
- Brushed finish



6.4 Finishes - Unformed

- Surface levelness/flatness
- Surface tolerances (CSTR 34)

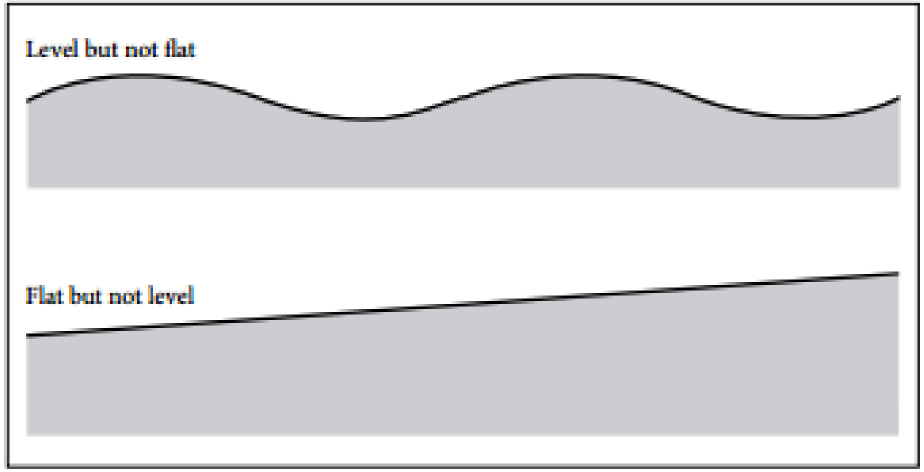


Figure 3.1: Flatness and levelness.

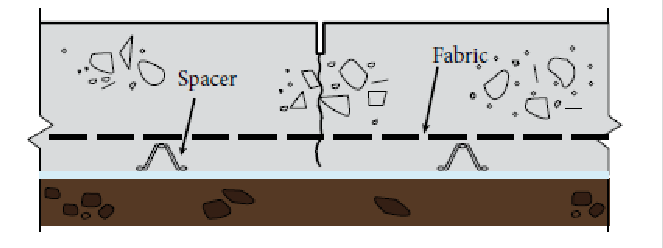
6.5 Joints

- Why do we need joints ?
  - Concrete expands and contracts due to thermal movements.
  - Concrete shrinks due to moisture loss in the hardened (and plastic) state.

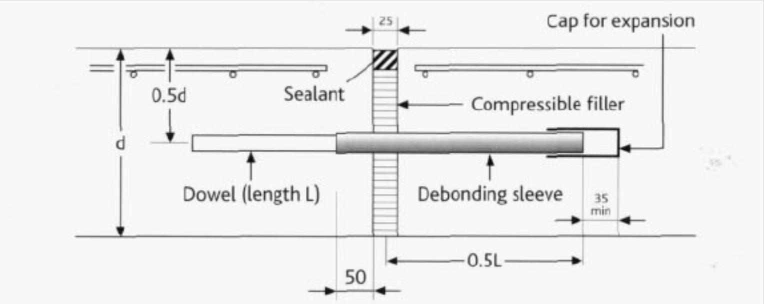
- Restraint (external or internal) limits free movement.

6.5.1 Joints - types

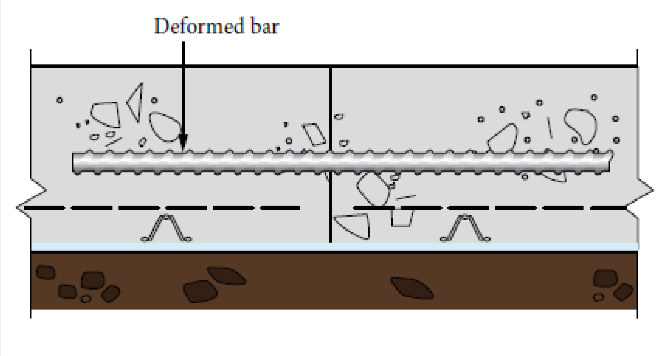
- **Contraction Joints**
  - Placed to accommodate the contraction of concrete – either induced or formed.



- **Expansion Joints**
  - Placed to accommodate the expansion (in addition to contraction) of the formed concrete.
  - Incorporates compressible filler.



- **Construction Joints (Day Joints)**
  - Placed where works temporarily finishes and when a movement joint is not required.



6.5.2 Joints - Construction

6.5.3 Joints - Formed

6.5.4 Requirements for Successful Joints

- Surface of hardened concrete must be clean and free from laitance
- Surface of hardened concrete should have exposed aggregate finish
- Fresh concrete must be place and compacted so that it bonds properly to prepared surface of previously laid concrete
- Joint should form a clean line on the surface

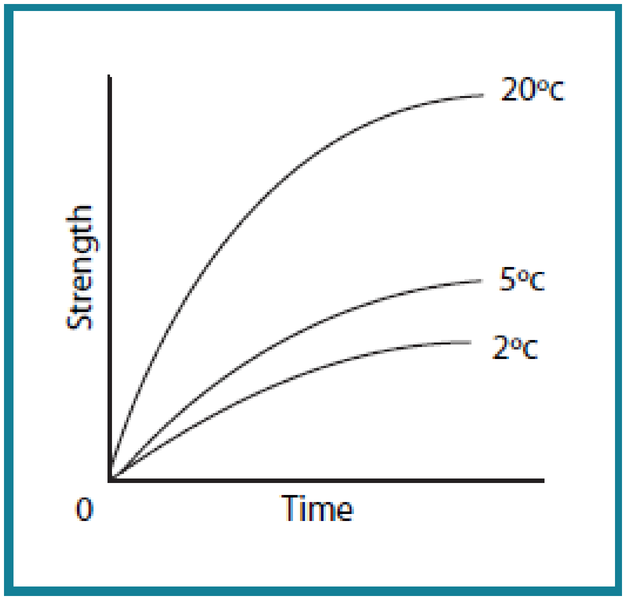
6.6 Cold & Hot weather work

- Cold < 5° C and falling – Placing not recommended (unless precautions in place)
- Cold 3° C and rising – placing possible

- Hot > 30°C – Placing often prohibited (EN 206)

6.6.1 Weather - Issues

- Effects on :
  - Setting & hardening
  - Strength development (early)
  - Surface drying/plastic cracking
  - Formwork striking



6.6.2 Thermal Issues

- Cement / water reaction (hydration) is exothermic
- Internal temperature rise : possible range of 9 – 12 degrees C per 100 kgs of cement in mix.
- Thermal gradient created if external face/surface is much cooler
- Internal restraint – causes thermal cracking as external surface layer cools & contracts
- Depends on :
  - Thickness of element
  - Shutter material
  - Stripping time
  - Cement type and ambient temperature

6.6.2 Thermal Issues – Thermal Cracking

Section thickness (mm)	Steel formwork Cement content (kg/m³)				18-mm plywood formwork Cement content (kg/m³)			
	220	290	360	400	220	290	360	400
< 300	5-7	7-10	9-13	10-15	10-14	14-19	18-26	21-31
500	9-13	13-17	16-23	19-27	15-19	20-27	27-36	31-43
700	13-17	18-24	23-33	27-39	18-23	25-32	34-43	40-49
≥1000	18-23	24-32	33-43	39-49	22-27	31-37	42-48	47-56

Note
Formwork is left in position until the peak temperature has passed
Concrete placing temperature, 20C
Mean daily temperature, 15C

- Temperature differential less than 20°C to avoid internal cracking
- If section less than 500mm, use steel formwork and strip earliest possible
- If section more than 500mm may have to:
  - Reduce cement content
  - Use timber plywood form
  - Use retarder or high GGBS substitution
  - Thermally insulate all surfaces

6.7 Cold Weather Concreting

- Concreting should not start when the air temperature is 5ºC and falling and should only begin when the temperature is at 3ºC and rising.
- Fresh concrete should never be placed on or against frozen ground.
- Reinforcing bars and shuttering must be free of ice and snow.
- Cover and insulate the concrete where possible.
- If concrete has to be placed it should be organized so that it is done as quickly as possible.
- **Frost blankets** should be used to provide insulation and protection for exposed concrete surfaces.
- Wind breaks will reduce wind chill and evaporation and help lower heat loss especially from slabs.
- Heaters may be necessary to provide continuous heating to the concrete to maintain heat.
- Increasing the cement content or grade of concrete can generate more heat in the concrete; consider the use of air entrainment, polypropylene fibres or accelerator.

7. Summary

1. Introduction
2. Execution Standards (IS EN13670)
3. Falsework & Formwork
4. Reinforcement
5. Prestressing
6. Concreting