bulletin 41

state-of-art report

Treatment of imperfections in precast structural elements

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State-of-art report
prepared by Task Group 6.8

November 2007

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Cover images (clockwise from top left): prestressed roof beam, columns, TT-units, sandwich-wall panels (photos provided by the Finnish Concrete Association).

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Foreword

Nothing is perfect! Flaws and quality deviations are inherent also in construction work and in prefabrication. Analyses of the imperfections and of their impact on precast concrete units' performance – with respect to safety, serviceability, durability and aesthetics – show that they can be accepted or remedied, in most cases. Nonetheless, the procedures for covering such aspects are rather uncertain and time-consuming, since the matter, in general, is not covered by codes of practice.

In realizing that a comprehensive approach to the problems, their implications and how to deal with them, would be worth exploring and making known to the profession, *fib* Commission 6 *Prefabrication* activated Task Group 6.8 "Treatment of Imperfections" for the drafting of this State of the Art Report, which tries to define the more involved and discussed aspects and to provide answers to the various questions that arise most frequently.

This report is based on many years of experience in the field and it considers geometric deviations, finishes, surface appearance, deformations, cracks and accidental damage.

Excellent graphic documentation is provided on the various types of precast elements, such as beams, columns, load-bearing wall panels, hollow core slabs, double tee slabs, solid planks and beam and block slabs.

fib Commission 6 and TG 6.8 wish to express their gratitude to all of the organisations for their kind permission to reproduce figures and texts, and especially to the Prestressed Concrete Institute (PCI), the Finish Concrete Association and the International Council for Building Research Studies and Documentation (CIB).

Prof. Marco Menegotto
Chair of *fib* Commission 6

Prof. José Calavera
Convenor of Task Group 6.8

Contents

1 Introduction

Imperfections in concrete structures are impossible to avoid and the personnel involved in construction should know how to deal with them.

Imperfections can range from minor surface blemishes to major structural defects. Because many imperfections are at the limits of specified quality deviations, or are not included in the acceptance criteria, the problem is more complicated than a decision between rejection or acceptance.

Precast concrete structural members, reinforced or prestressed, are widely used and often a preferred solution in the construction industry. The proven strength, quality and performance characteristics of precast concrete members make them ideal for wide a variety of civil engineering and construction applications. In addition to this and their inherent fire resistance, they offer many advantages over other materials by way of speed of erection and the creation of an immediate working platform.

Precast concrete, structural and architectural members are usually manufactured by skilled labour in a controlled environment and are renowned for their high quality. However there are occasions when the quality of the manufactured product is not what is intended in the design. This can be due to many causes such as weather effects, quality of constituent materials, handling and erection.

This document describes the most common types of imperfections encountered during manufacture, stacking, transport and erection and suggests a number of possible remedial actions. The remedial actions depend on the severity of the imperfection, the feasibility of repair and the consequences on the intended use of the concrete member.

2 Scope

This document deals with precast concrete elements that do not meet the quality as intended in the design. It compares imperfections in quality to the specified requirements so that the effect of the imperfection can be evaluated. Recommendations are provided on methods to prevent such imperfections, the effect they can have and any necessary actions for rectification.

The scope of this document covers prefabricated concrete members made of reinforced or prestressed normal weight concrete. Products include beams and columns, concrete walls, hollow core slabs, double tees, planks and beams for beam and block floors. Water retaining structures are outside the scope of this document.

Imperfections from the manufacturing stage to the installation on site are covered. Imperfections that occur after erection or that occur due to lack of regular maintenance of the concrete surface are not covered.

This document should be read in conjunction with the relevant codes and standards dealing with precast concrete products.

Specific cases shown in chapter 5 are for guidance; all imperfections which have influences to load bearing capacity should be checked by the responsible structural engineer.

3 Type of defects

3.1 Geometrical deviations

3.1.1 Prior considerations

Precast concrete members are industrial products and as such their manufacture is subject to a system of dimensional tolerances associated with the maximum allowable dimensional deviations in effect. On the site, however, precast members are often combined with in situ concrete elements, normally erected in accordance with traditional building practice, in which greater allowable dimens ional deviations - and hence wider tolerances - prevail.

As a result, a combined system of tolerances must be devised, making allowance for both types of construction to minimize worksite complications. Developer, engineer or architect, contractor and precast manufacturer all share one aim: to ensure quality construction.

Consequently, the relationships and responsibilities of the various parties concerned must be clearly defined and a fluent exchange of information and effective communication must be established.

As noted above, tolerances should be viewed from the perspective of the works as a whole and not the precast elements only, although each family of elements should logically be designed in accordance with levels of precision that are readily attainable in the respective type of construction.

Practical experience accumulated over many years shows that in general construction can accommodate dimensional deviations much greater than might initially be believed without generating operational problems, structural hazards, or aesthetic concerns.

The idea that construction entails following unnecessarily strict tolerance limits springs from the fact that the construction industry has unfortunately financed very few deviation measurements on real construction sites. The outcome has been a general unawareness that the deviations actually existing, which are often considerably greater than what intuition might allow, ultimately occasion no practical problems.

3.1.2 Recommended references

A document such as this, which addresses precasting of a wide variety of different products, cannot feasibly formulate a detailed system of tolerances, in light of the very broad range to be covered.

A number of systems are currently in use for local products, most notably the CEN series of product standards. PCI also publishes a general reference that covers practically all precast structural concrete titled "Tolerance Manual for precast and prestressed concrete construction". [1]

3.1.3 Practical application of tolerance systems

The on-site application of different tolerance systems calls for large doses of good judgement and practical experience.

A tolerance system cannot be envisioned or used as grounds for rejecting acceptable products and even less as for imposing the acceptance of flawed elements. On the contrary, non-conformities for reasons of tolerance should only lead to rejection if the deviations recorded are not only larger than allowed in the respective standards, but actually jeopardize construction in some way.

The following example illustrates this principle.

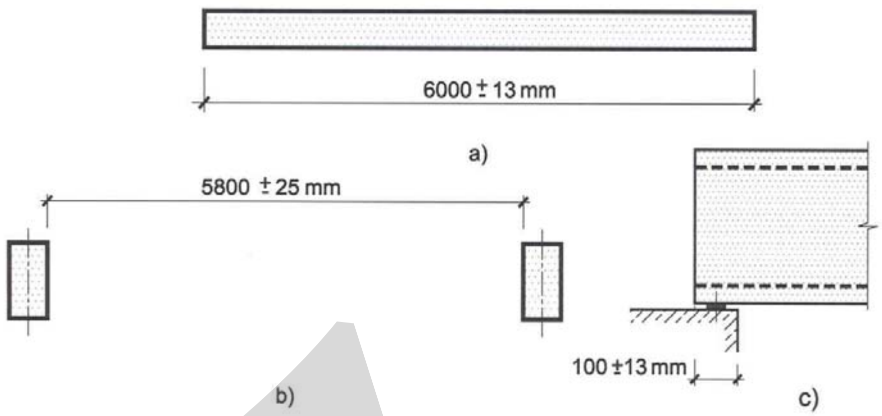


Figure 3-1: Example of tolerances applied to a precast element

Figure 3-1 depicts a precast hollow core slab resting on two cast-in-place structural beams. Figure 3-1 a) shows the span dimensions and allowable deviation. Figure 3-1 b) gives the clear distance between beams. Finally, the support length and respective tolerance are set out in Figure 3-1 c).

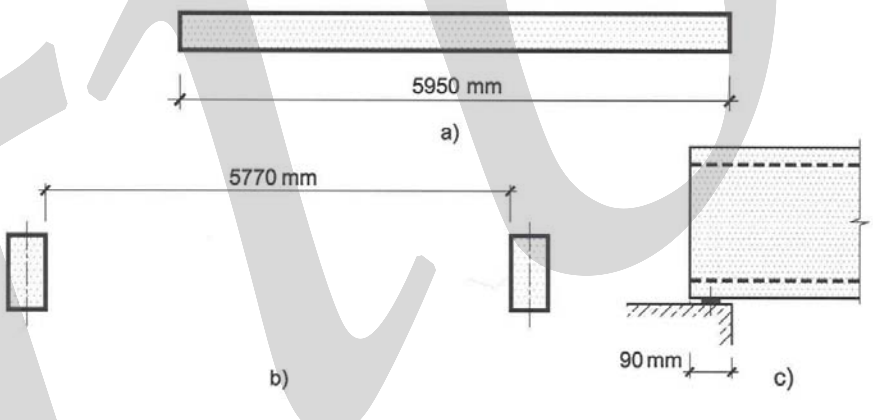


Figure 3-2: Example of real deviations in a precast element

Assume that, as illustrated in Figure 3-2, the deviations in both the precast and in situ members are greater than the pre-defined tolerances.

According to Figure 3-2 a), the actual manufactured length of the hollow core slab is 5950 mm, i.e., less than allowed pursuant to the tolerance specified in Figure 3-1. Figure 3-2 b), in turn, shows that the clearance between the two beams is 5770 mm, likewise deviating more than allowed in Figure 3-1. However, since the flaws in both the precast and the in situ members entail reductions in the design dimensions, the resulting slab support length on the beam, at 90 mm, does in fact conform to the tolerance limits indicated in Figure 3-1 c). Since the two flaws identified obviously have no adverse effect on construction, neither the precast nor the in situ part of the work should be rejected.

Based on the premise that if construction is to be an effective and efficient process, acceptance or rejection of a product must relate to the overall effect on construction rather than individual compliance. Taking any other approach has proven to be ineffective and impractical.

3.2 Surface texture – Aesthetics

Surfaces of precast concrete components can have imperfections that do not follow the specifications of the client. The reasons for these imperfections are usually failures in the pouring process, inadequate quality of the mould, unsuitable form agent or the miss-use of concrete additives.

The main quality demands for concrete surfaces concern evenness of surface, colour variation and cracking.

3.2.1 Evenness of surfaces

The most often seen imperfections are indentation, pores, fins, loose cast, waviness, nodes and cavities. Comparison of these imperfections with the specified surface classification helps evaluation of acceptability and need for repair.

The following tables 3-1, 3-2, 3-3 and Figure 3-3, taken from [2], show types of imperfections and acceptability limits for each surface classification. Class C is recommended only for hidden concrete surfaces (e.g. foundation units and surfaces behind suspended ceilings) and class AA only for high quality buildings or when the viewing distance is a maximum of 5 meters.

Quality factors		**Requirements**			
		Class AA	**Class A**	**Class B**	**Class C**
Node					
maximum height	mm	1	3	6	6
maximum width	mm	2	9	20	20
maximum amount	amount/m^2	10	20	40	40
Cavity					
maximum depth	mm	2	4	7	7
maximum width	mm	4	9	15	15
maximum amount	amount/m^2	10	20	40	40
Indentation	mm	0,5	2	5	5
Fin or scar at the mold seam					
maximum height or depth	mm	1	2	4	4
maximum width	mm	2	3	6	6
maximum amount (concerns also a repaired joint)	% of the length of mold seams	5	20	30	30
Pores of the horizontally cast surfaces, ∅ ≥ 2 mm				∅ ≥ 5 mm	∅ ≥ 5 mm
maximum diameter and depth	mm	5	8	10	10
maximum total amount	amount/m^2	20	40	80	160
Pores of the vertically cast surfaces, ∅ ≥ 2 mm				∅ ≥ 5 mm	∅ ≥ 5 mm
maximum diameter and depth	mm	7	10	12	12
maximum total amount	amount/m^2	40	60	100	200
Loose cast or another defect on the horizontally cast surfaces (always has to be repaired)					
maximum size	m^2	not allowed	0,1	0,3	0,6
maximum amount	amount/100 m^2	not allowed	1	2	4
Loose cast or another defect on the vertically cast surfaces (always has to be repaired)					
maximum size	m^2	not allowed	0,2	0,3	0,6
maximum amount	amount/100 m^2	not allowed	2	2	4
Curvature and waviness on the surface					
maximum measure deviation	mm/1,5 m	2	5	8	8

Table 3-1: Defects and qualification of surfaces poured against mold [2]

Quality factors		**Requirements**					
		Low blast		**Medium deep blast**		**Deep blast**	
		Class AA	**Class A**	**Class AA**	**Class A**	**Class AA**	**Class A**
Node maximum height maximum width	 mm mm	 1 3	 3 10	 2 5	 5 15	 3 6	 5 15
Cavity maximum depth maximum width	 mm mm	 2 5	 6 10	 4 10	 10 20	 6 12	 10 20
Indentation	mm	1	3	2	3	3	4
Fin maximum height maximum width	 mm mm	 1 2	 3 5	 2 4	 3 5	 2 4	 3 5
Pores, ∅ ≥ 3 mm [1)] maximum diameter maximum total amount	 mm amount/m^2	 5 80	 8 100	 5 80	 8 100	 – –	 – –
Curvature and waviness maximum measure deviation	mm/1,5 m	3	5	4	6	5	7

1) Occasionally (e.g. in the unit corners) there can be allowed 50 % larger diameter and double amount of pores.

Table 3-2: Defects and qualification of sand blasted surfaces [2]

Quality factors		**Requirements**
Cavity maximum depth maximum width	 mm mm	 2 5
Indentation	mm	1
Pores, ∅ ≥ 3 mm [1)] maximum diameter maximum total amount	 mm amount/m^2	 5 80
Curvature and waviness maximum measure deviation	mm/1,5 m	3

1) Occasionally (e.g. in the unit corners) there can be allowed 50 % larger diameter and double amount of pores.

Table 3-3: Defects and qualification of polished concrete surfaces [2]

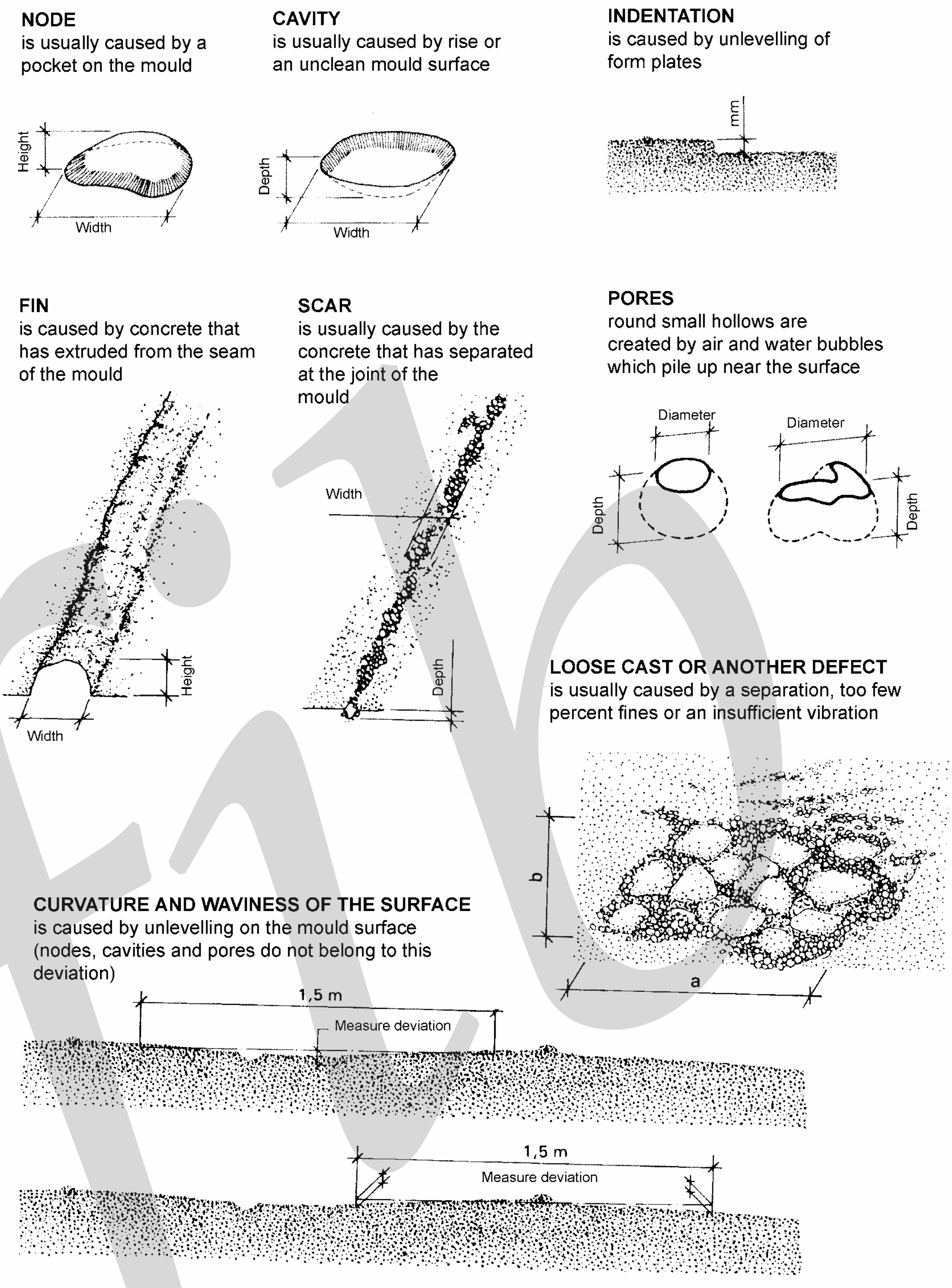


Figure 3-3: Defects with mold surfaces [2]

3.2.2 Colour and darkness variation

With the use of different coloured pigments and aggregates concrete can be produced with almost any kind of coloured concrete surfaces. Certain colour variation is a natural feature of concrete surfaces. Even a grey concrete surface has variation in darkness and colour.

The lightness of concrete surface is influenced by cement type, mould surface, colour of fine aggregate and water-binder-ratio. ISO 2470 standard gives a classification of lightness from 0 to 100. Zero means black and 100 white. The lightness of cement varies so that white cement is 75-80 and normal Portland cement 24-30 in the classification.

Measuring systems like CIELAB Colouring System can be used in evaluation of reference surfaces both for grey and coloured concrete. These systems are very accurate but involve considerable effort and cost and can usually only be justified on monumental type structures where high levels of colour control are required.

At a more practical level colour controls can be specified on a concrete surface by reference to a test panel or by reference to a chart that shows a range of tonal colours.

For grey or light coloured concrete surfaces, CIB W-29 report no. 24 "Tolerances on blemishes of concrete" [14] can be used to assess the acceptability of the finished surface. This document includes a tonal chart giving seven separate tones ranging from light to dark, similar to the example shown in Figure 3-4.

The acceptability of the surface colour will vary according to the specified class of surface finish. For Class AA and Class A surfaces, the maximum allowable colour variation is two tones and in class B surfaces three tones. The comparison is made when the concrete is dry and in the shade and viewed from at least 3 m from the surface.

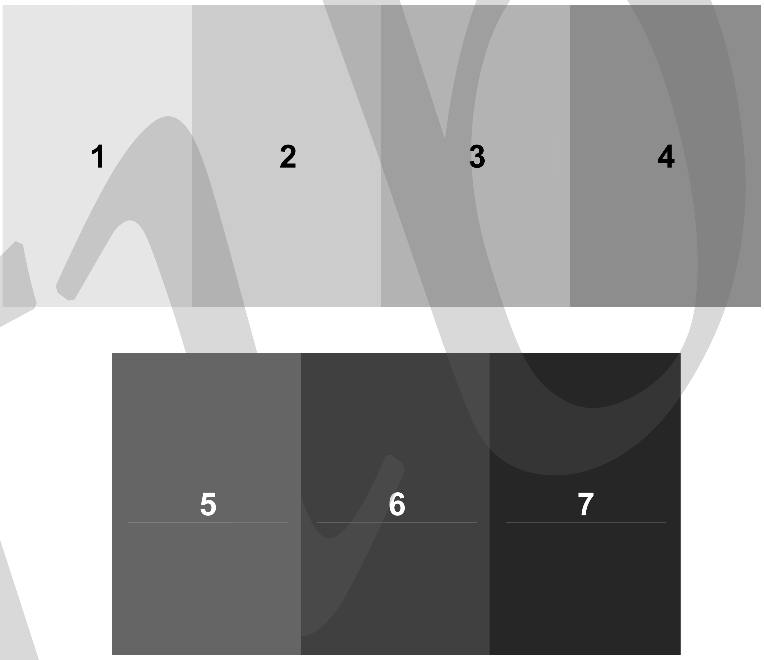


Figure 3-4: Principle of grey colour classification according to CIB report no. 24 [14]

For coloured concrete surfaces the most practical control method is by the use of a test panel. This should be provided as part of the project documentation and can then be used as the control mechanism. The panel should be large enough to show the range of acceptable tones.

The variations between the test panel and building surface can be inspected and evaluated against the specified acceptance criteria. Table 3-4 describes typical colour imperfections and causes.

Imperfection	Description	Probable cause
Colour variation across surface	Variation in colour of the surface	**Materials** Cement type or quality changed. Change in source of materials. Variation in admixtures. **Concrete mix** Variations in mixing procedures.
Aggregate transparency	Surface appears mottled with dark areas similar to the size and shape of the course aggregate.	**Formwork** Too flexible and resulting in a pumping action during compaction **Concrete mix** Insufficient fines content. Gap grading of sand. **Placing methods** Excessive vibration.
Negative aggregate transparency	Surface appears mottled with light areas similar to the size and shape of the course aggregate.	**Materials** Aggregate dry or highly porous. **Curing** Inadequate curing allows rapid surface drying.
Hydration discolouration	Variation in the shade of the surface due to moisture movement within the plastic concrete. Staining and discolouration tend to be worse at the top of a lift and at construction joints.	**Formwork** Variable absorbency of surface. Leaking through joints. **Concrete mix** High water cement ratio. High bleed mix. **Release agent** Uneven or inadequate application. **Curing** Uneven curing.
Segregation discolouration or sand runs	Variation in colour, shade or texture due to separation of fine particles and bleeding at the surface of the form. Results in a flecked surface appearance.	**Formwork** Low surface absorption. Water at the bottom of the form. **Concrete mix** Lean mix with high water-cement ratio. Unsuitably graded aggregate. **Placing methods** Excessive vibration of concrete. Low placement temperatures.
Dye discolouration or contamination	Discolouration due to contamination of materials.	**Formwork** Stains, dyes, dirt on formwork, timber stains, rust from reinforcement or metal components. **Release agent** Impure of improperly applied. **Materials** Dirty or contaminated. **Curing** Impure curing compounds. Dirty curing water. Dirty curing covers.

Table 3-4: Typical colour imperfections and causes

Imperfections in coloured concrete surfaces are very difficult to rectify. Rectification methods will depend on the class of finish required and the type of concrete used and can vary from project to project.

For grey colour surfaces rectification may range from rubbing or stoning the surface for minor discolouration through to coating with a cementitious based applied finish in cases of severe imperfections. For coloured surfaces rectification options are very limited and anything other than a minor imperfection may require an applied finish over the whole surface.

To give a more homogenous colour of the surface it is recommended that hardened cement paste be remove from coloured surfaces by retarding, some blasting or acid treatment.

3.2.3. Cracking of surfaces

Cracks in the concrete surface can influence the durability of the structure or/and be an aesthetics problem. Cracks under 0.05 mm wide are called micro-cracks and can usually be disregarded. They are not dealt with in this document. Cracks 0.3 mm wide or more usually need some form of treatment to overcome durability and/or aesthetic problems.

Table 3-5 taken from [2] shows some limiting values for visual cracks. The first figure in the table means the crack width and the second total-length of crack in the max. area of 1 m^2. Cracking under 0.05 mm is not taken into account. On coated surfaces cracks cannot be seen after coating.

Durability requirements must be evaluated separately.

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

Table 3-5: Maximum size and amount of visual cracks in concrete surfaces [2]

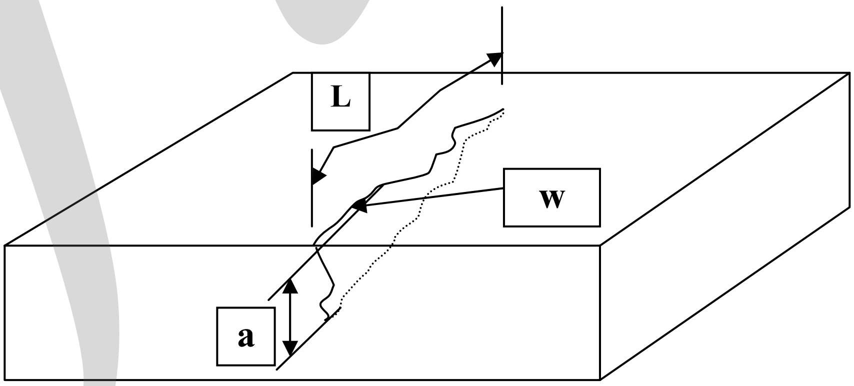


Figure 3-5: Control of surface cracks (L= length, w= width, a= depth). Crack length is evaluated as a cross line with steps of 150mm. [2]

3.3 Deflection and camber

Concrete is a material that has time dependent characteristics. Creep and shrinkage occur over time and are fundamental causes that have an influence on deformations.

It is very complex to evaluate the exact deformations of a structure. More so if the structure is built with precast members that have a composite configuration of in situ and precast concrete where parts are fabricated with different concretes that have different ages and strengths and therefore different creep and shrinkage characteristics. These aspects, added to the normal complexities of concrete makes it difficult and uncertain to evaluate exactly the time dependent deformations of a structure.

Actual deformations may differ from the estimated values, particularly if the values of applied moments are close to the cracking moment. The differences will depend on the dispersion of the material properties, on the environmental conditions, on the load history, on the restraints at the supports, ground conditions, etc. Besides vertical and horizontal loads temperature, humidity and chemical agents are important to evaluate deformations.

Normally deformation with time is evaluated by multiplying instant load deformation by a coefficient that takes into account creep, shrinkage, reinforcement content and duration of load. In floor slabs for normal buildings long-term deformation is about 2.8 times instant deformation. To simplify this process most texts give approximate ways to compute actual deformations. It is also common that they give recommended minimum depths of the structural part to avoid the need to calculate deformations.

Control of deformations is important for structural reasons. Deformations also have to be controlled for reasons relating to the use of the structure and these restrictions are normally the ones that limit the design. For example in buildings, restrictions are required to control deformations of partitions and facades. In bridges restrictions are required to control the comfort of occupants of vehicles. This is why some texts restrict deflections that have an influence on the use of the structure.

Camber is the upward deflection of an element due to prestressing. This deformation is very dependent on the strength of the concrete at prestressing release, tension state of the element, humidity, temperature and time. Therefore calculation of camber depends on many factors that make it difficult to produce an accurate result. For example time in storage has more influence on camber than any other factor.

Camber limits at the time of erection are frequently specified for precast elements. However this provides little guidance on the performance of the element within the completed structure. Insitu concrete toppings can affect the deformations and can be used to mask excessive cambers. When precast elements are placed adjacent to each other, relative deformation may need to be limited due to aesthetic reasons or to functional reasons if there is no in situ concrete connecting them.

In bridges camber for self-weight and live load deflection are relevant.

Information about deflections for members resisting vertical loads, either beams or slabs, is provided in many texts, but there is little information about deformations of vertical members due to horizontal loads.

Limitations for deformations and camber can be found in standards EN 13225 [11] and EN 1992-1-1 [7].

3.4 Cracks

3.4.1 Introduction

Cracking in concrete can be the result of one or a combination of factors, all of which involve some form of restraint. The most common causes of cracks include drying shrinkage, thermal contraction and expansion and applied stresses. Forces can build up inside the concrete due to any of these factors, and when the forces exceed the strength of the material, cracks develop. Cracking is influenced by the quality of the constituent materials of the concrete, weather conditions, curing, manufacturing process and handling.

Cracks are inherent in reinforced concrete and their occurrence does not necessarily imply problems. While cracks are often more of an aesthetic rather than structural concern they can be an indication of external problems including inadequate design or overloading.

For precast concrete elements, cracks can be divided into the following types:

- thermal cracks,
- plastic settlement and autogenous shrinkage cracks,
- drying shrinkage cracks,
- mechanical cracks.

3.4.2 Thermal cracks

Concrete grows and shrinks with temperature changes. Thermal cracking occurs when the tensile strain induced during the period of cooling is greater than the tensile strain capacity of the concrete. This is particularly important during the plastic stage of the concrete.

3.4.2.1 Factors affecting thermal cracking

(1) Cement type and content

Hydration of cement is an exothermic reaction. The total amount of heat and rate of heat generation is a characteristic of the type of cement and the cement content. The less heat generated the less potential for thermal cracking of the concrete.

Concretes based on Sulfate Resistant Portland Cement (SRPC) generally give lower temperature rises than equivalent Portland Cement based concretes. Concretes based on cement replacement materials such as Pulverised Fuel Ash (PFA) or Ground Granulated Blast furnace Slag (GGBS) can help to reduce peak temperatures.

Increasing the cement content generates more heat and causes concrete to heat up and subsequently expand. Cement contents are dictated by strength and durability requirements. High cement contents can lead to other problems such as increased drying shrinkage and over cohesion.

(2) Aggregate type

Concrete with a low coefficient of thermal expansion greatly reduces the risk of thermal cracking. The coefficient of thermal expansion of concrete is dependent on the coefficients of thermal expansion of the aggregates.

(3) Curing method

The curing method of the concrete can also have an influence on thermal cracks. Precast concrete elements are usually covered with polythene sheets until the concrete has reached a desired compressive strength. This minimises the rate of temperature variation and reduces the likelihood of thermal cracking.

3.4.3 Plastic settlement and autogenous shrinkage cracks

Plastic settlement cracks appear immediately after the concrete has been placed and are caused by bleeding (the displacement of water upwards) and settlement of the concrete.

Autogenous shrinkage cracking occurs when the concrete is either still wet or when it is still very immature.

3.4.4 Drying shrinkage cracks

Long term drying shrinkage is caused by water leaving the gel pores within the cement paste of the concrete. This creates internal stresses which if higher than the tensile strain capacity of the concrete will lead to cracking. Cracks result when the rate of evaporation of water from the surface of the concrete exceeds the rate at which water bleeds to the surface. This situation is common when there is hot, dry and/or windy weather or when setting of the concrete is delayed.

Drying shrinkage usually occurs as follows:
- 14 to 34 % of the ultimate shrinkage occurs within two weeks;
- 40 to 80 % of the ultimate shrinkage occurs within three months;
- 66 to 85 % of the ultimate shrinkage occurs within one year.

Factors affecting the drying shrinkage include:
- aggregate to paste ratio;
- volume to surface area of the component;
- ration of water to cementitious material;
- pore size distribution;
- type and amount of cement;
- the amount of coarse and fine aggregates.

Cracking can be reduced using a concrete mix design with the minimum amount of water necessary to distribute the paste without voids.

3.4.5 Mechanical cracks

Mechanical cracks can be due to accidents or mishandling of the concrete elements or inadequate design to withstand applied actions. These are usually postproduction problems. Cracks that occur while stacking and handling the product could be the result of one of the following:
- overload in the factory;
- lifting problems;
- stacking error.

Cracks that occur during erection may indicate a more serious problem and should be referred to the designer for assessment.

3.5 Spalling, splitting and bursting

3.5.1 Introduction

The types of cracks relate to transference of prestressing forces to concrete members. The most typical use of prestressing in precast concrete construction is pretensioning, in which prestressing strands are anchored to concrete by bond of the strands to the concrete.

Spalling splitting and bursting cracks can occur in the end zones of prestressed elements where the concentrated stressing forces are distributed to a linear stress distribution across the concrete section. This zone is defined as the "transfer length". In EC-2 [7] "transfer length" is called "dispersion length". See Figure 3-6.

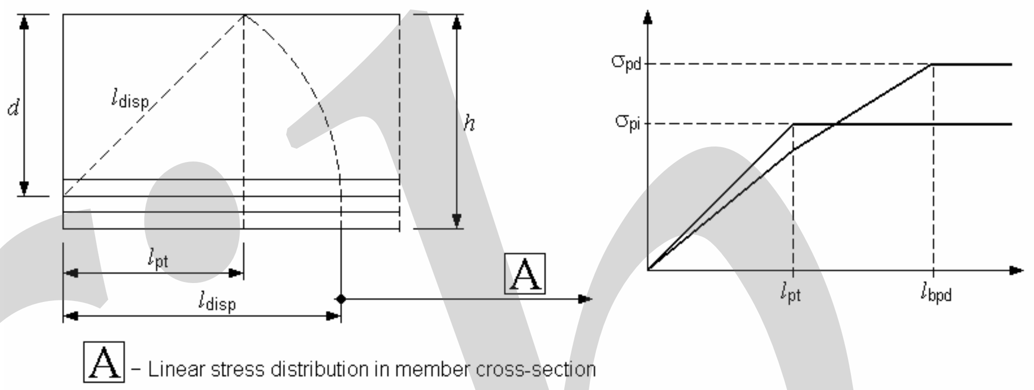


Figure 3-6: Transfer lengths according to EC-2 1-1 [7]

In a prestressed element the compressive and tensile stresses are not distributed linearly. This frequently gives peak stresses greater than allowed for the tensile strength of concrete in a linear stress distribution. It also gives other tensile stresses perpendicular to the axis of the element. Figure 3-7 shows the types of cracks that can occur in the end zone of a prestresssed element [4].

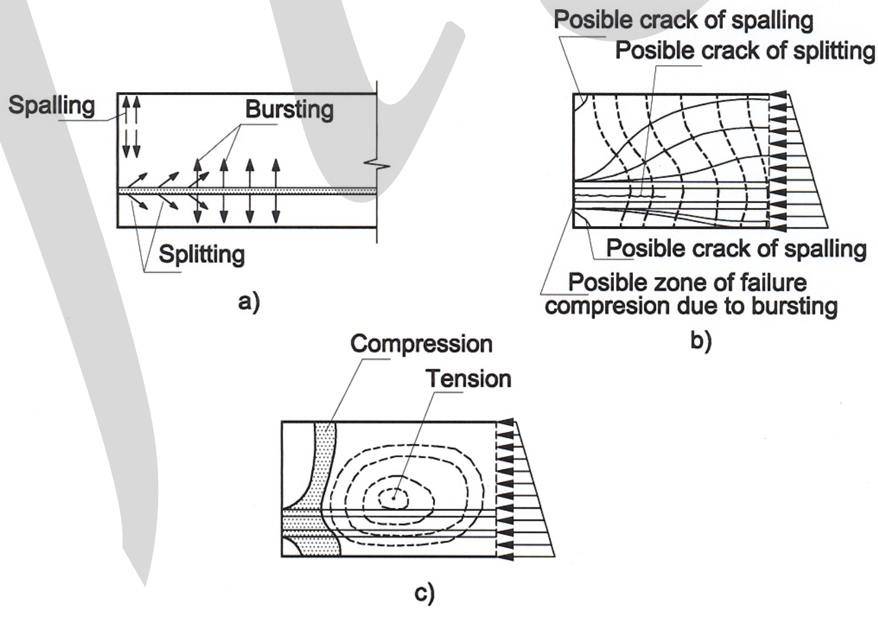


Figure 3-7: Transfer stresses [4]

3.5.2 Splitting cracks

Splitting cracks result from tensile forces in the prestressing tendon being transferred to the concrete by bond. They can only occur in pre-tensioned elements.

3.5.3 Bursting cracks

Bursting cracks are due to the primary splitting tensile force. They occur very close to the prestressing tendons and generate circumferential tensile stresses. They can occur in both pre-tensioned and post-tensioned elements.

3.5.4 Spalling cracks

Spalling cracks result from the secondary splitting force. The tensile stresses in this case are mainly vertical and very close to the end of the element. They can occur in both pre-tensioned and post-tensioned elements.

3.6 Accidental damage

Precast elements may suffer accidental handling damage at any time, from manufacture to on-site assembly. Such damage does not cover flaws consistently arising in specific situations (such as systematic cracking during hoisting), which are, rather, an indication of flawed design or inappropriate handling. Accidental damage occurring during manufacture, storage, shipping or assembly is difficult to classify and enumerate for the wide range of situations involved.

Many types of flaws due to accidental damage may be treated as described in the general discussion of remedial action for the various elements set out in Chapter 5. Major damage occurring when elements are dropped during assembly, or involved in shipping accidents, fire or similar, however, call for specific case studies.

4 General aspects classification

4.1 Level of safety required

The level of safety required is defined by the codes to which the structure is designed.

Previous studies [8] show that essentially the same level of safety is attained with all Codes, and in practice the differences between them are due more to the corrective safety coefficients that depend on each country's construction quality, rather than to conceptual issues.

Any flaw, whether in dimensions, material quality or structural engineering, may translate into a loss of strength capacity. The primary problem is to establish the limit up to which the member in question is technically acceptable and requires no further action. This does not, naturally, preclude financial adjustments, since developers should not be expected to pay the same price for flawed but acceptable components as for conforming elements. Even where this first threshold is crossed, however, certain elements may still be technically acceptable, subject to repair or strengthening. Finally, there is a second and final threshold beyond which rejection is inevitable because the element is not technically acceptable and repair or strengthening is either impractical or technically impossible.

In the event of a flawed element or series of elements, then, the impact of the flaw must be determined in terms of strength capacity loss in the respective member.

Where the characteristics and extent of the flaw are known, such as low concrete strength or missing reinforcement, the element or elements can be re-engineered to compare their actual capacity with the specified requirements. The designer can then make a rational judgement on the use or otherwise of the elements.

Where the characteristics of the flaw are not known a practical and realistic approach must be found to solve this problem. The construction industry is such that there is insufficient statistical data available to conduct a pure and simple probabilistic study that would provide a scientifically sound basis for determining the safety of flawed elements.

One such practical approach draws heavily from [9] and essentially addresses two scenarios:

- Cases in which a number of elements are flawed and only semi-probabilistic information is available on the consequences of the flaw in question. One example would be a reduction in the concrete strength of an entire lot of elements revealed during routine specimen sampling.
- Cases, usually affecting a very small number of elements, in which deterministic information can be obtained on the flaw, because it is financially and practically possible to run an in-depth investigation of material quality, reinforcement arrangement, actual element dimensions and so on.

In Annex A.1 more detailed information is included.

4.2 Durability

Flaws in precast element design, manufacturing, shipping or assembly often have no impact on strength but do affect durability. Although this problem is extremely difficult to quantify given the present state of the art, conditions that reduce element durability can often be compensated with – usually surface treatments, although any such solution must be subject to an agreement between the precaster and the client.

Another possibility would be to study the service life of the member, analyzing the specific flaw and actual condition of the element, in as much as the concretes used for precasting (thanks to properties such as cement content and W/C ratio) are generally more durable than their cast-in-place counterparts. Another consideration to be taken into account in this context is the surrounding environment. The method suggested for such calculations is given in DuraNet "Service Life Design of Concrete Structures From Theory to Standardisation" (2001), *How to incorporate probabilistic service life design in the CEN standards*.

Once the service life and actual conditions are defined, the design engineer is in a position to decide whether to accept the flawed element or elements or study the possibility of adopting one of the protective measures mentioned above.

4.3 Aesthetic issues

Much of the damage to elements caused during shipment and assembly affects their appearance only. Aesthetic standards naturally vary widely from one case to another and even within the same structure or type of element, requirements are highly location-dependent.

One particularly important issue is the effect of possible cracks, for which two considerations should be addressed:

- As a general rule, most people can see a crack if its width, measured in millimeters, is the same figure as the distance, measured in meters, between the viewer and the cracked surface.
- Figure 4-1, extracted from reference [10], shows aesthetically admissible crack widths in terms of the minimum distance to the viewer and the class of the structure.

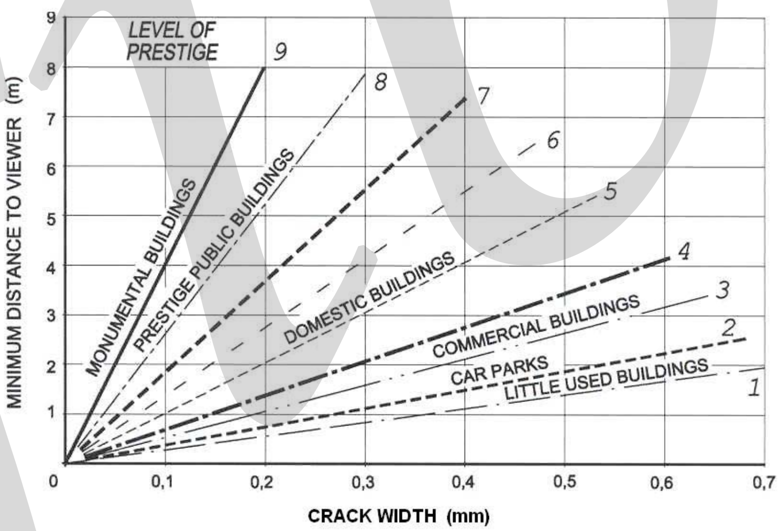


Figure 4-1: Aesthetically acceptable crack widths [10]

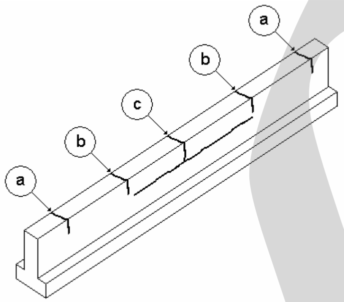
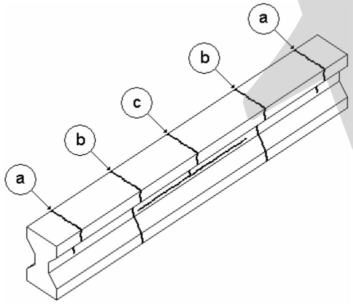
Notwithstanding the above, aesthetic flaws may often be repaired to restore the general appearance of elements to previously accepted aesthetic standards.

5 Specific cases

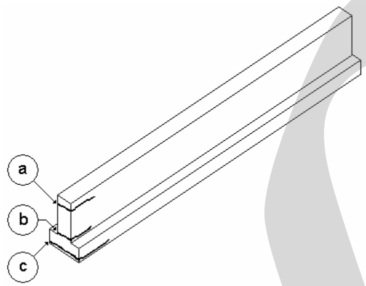
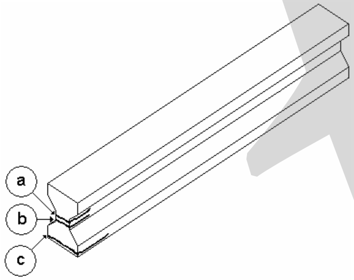
In the following chapters the specific cases of imperfections are shown, classified by structural elements. It is given in each case information about the cause, how to prevent it, the effect and the possibility of repair.

The contents about columns and beams (section 5.1), hollow core slabs (section 5.3) and double tee units (section 5.4) are based on the documents of PCI "Fabrication and Shipment Cracks in Precast or Prestressed Beams and Columns" [12] and "Fabrication and Shipment Cracks in Prestressed Hollow-Core Slabs and Double Tees" [13]

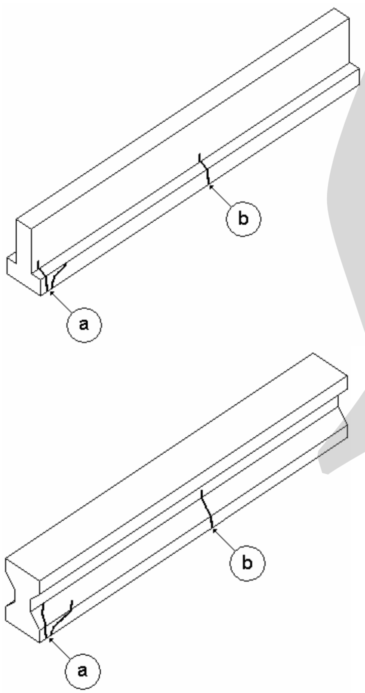
5.1 Columns and beams

Typical case	Cause	Prevention	Effect	Repair
TRANSVERSE CRACKS AT TOP OF BEAM These cracks are typically perpendicular to the longitudinal axis of the beam and usually extend across the top of the beam and are visible on the sides. In some cases they may extend the full depth of the beam or propagate along the beam near the centroid of the beam.  	**A) Improper design**		For simply supported beams the effect of cracks type 'b' and 'c' is minimal and they will tend to close with application of load. Crack type 'a' can affect the shear capacity, particularly if the crack occurs in a negative bending moment zone. (this could occur if the beam is incorporated into a continuous structure) In this case the capacity of the beam should be reassessed taking into account the actual crack locations and sizes. If a type 'c' crack extends horizontally along the web of the beam the capacity of the beam may be reduced and the design of the beam should be reassessed by the designer. Plastic cracks frequently occur in the cover zone above ligatures. They have minimal effect on structural capacity.	Minor cracks may not need repair unless the beam will be exposed to a corrosive environment. In this case pressure injection with epoxy should be considered. If the cracking results in a structural deficiency the options are to pressure inject with epoxy or in cases of severe cracking to reject the beam.
	Prestress uplift at midspan exceeds the top fibre tensile capacity. Cracks 'c'	Reduce midspan prestress and/or provide additional reinforcement to control cracking.		
	Lack of or inadequate debonding of bottom strands at end of beam. Cracks 'a'	Redesign beam with increased strand debonding and/or provide additional reinforcement to control cracking.		
	Inadequate top reinforcement. Cracks 'b, c'	Redesign beam with increased top reinforcement.		
	B) Improper production			
	Incorrect placement of top reinforcement. Cracks 'a,b,c'	Ensure that top reinforcement is correctly placed and held in position during casting.		
	Incorrect location of lifting points.	Ensure that lifting points are correctly located.		
	Drying shrinkage of the concrete.	Apply curing covers earlier and/or mist spray exposed surfaces with water.		
	Expansion of the mould due to early application of curing heat.	Allow longer time before applying curing heat to mould.		
	Low concrete release strength.	Increase concrete release		

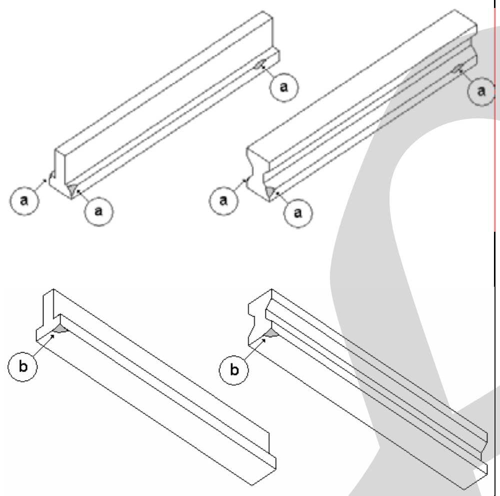
Typical case	Cause	Prevention	Effect	Repair
		strength.		
	Delayed detensioning of the component.	Detension strands as soon as concrete reaches strength. Do not allow heat-cured beam to cool rapidly before destressing.		
	Plastic cracking.	Commence curing earlier and/or modify mix design to minimize early moisture loss.		
	C) Improper handling			
	Incorrect support locations for storage. Cracks 'b'	Ensure that support points are correctly located.		
	Torsional displacement of the beam during handling.	Limit torsional stresses by modifying procedures to ensure that beam is not twisted during handling.		

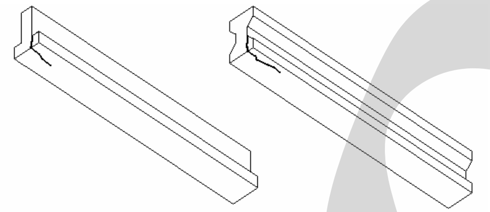
Typical case	Cause	Prevention	Effect	Repair
HORIZONTAL END CRACK IN WEB OR FLANGE These cracks usually begin at the end of the beam and can extend horizontally for a distance up to about one metre. They are frequently located in the horizontal plane of the strands and extend across the full width of the beam.	**A) Improper design**		If the crack does not coincide with prestressing reinforcement the effect is minimal. The end reaction provides a clamping force that will tend to close this type of crack. If the crack coincides with prestressing reinforcement there is a possibility that the strands have lost some or all of their bond. This could reduce the shear and flexural capacity of the beam at the end due to reduced prestressing force.	If the crack does not have structural implications it may be left unless it is an aesthetic issue or if the beam is exposed to a corrosive environment. In these cases epoxy injection or a coating should be considered. If the crack reduces the structural capacity of the beam the situation should be referred to the designer for assessment. Epoxy injection may be an option.
	Excessive prestressing force or uneven distribution of prestressing force.	Respace or debond some strands at end of beam to provide more even stress distribution.		
	Differential stresses between web and flange.	Provide additional confining reinforcement. Reconfigure or debond strands to provide more even stress distribution.		
	Inadequate confining reinforcement in the end zone.	Provide additional confinement reinforcement.		
	Inappropriate debonded strand configuration in association with lack of confinement reinforcement.	Modify debonding configuration and/or provide additional confinement reinforcement.		
	B) Improper production			
	Improper release of strands.	Modify strand release procedures		
	Improper detensioning procedure.	Adopt a method that allows slow release of strands.		
	Improper detensioning sequence.	Ensure prestressing force is balanced during release.		
	Detensioning sequence producing differential stresses between web and flange.	Modify detensioning sequence to minimize differential stresses between web and flange.		
	Low concrete strength at release.	Modify concrete mix design to obtain earlier design strength or delay detensioning until concrete has obtained design strength.		

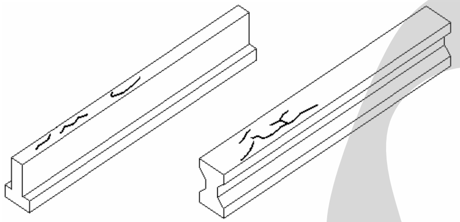
Typical case	Cause	Prevention	Effect	Repair
	Strand slippage.	Ensure strands are clean or ensure concrete has obtained design strength before detensioning.		
	Insufficient cover to bottom row of strands.	Provide adequate cover to strands.		
	Settlement of concrete below a concentration of reinforcement.	Ensure concrete is adequately vibrated. Allow time for initial concrete settlement and then revibrate concrete. Modify concrete mix design to increase flowability and minimize initial settlement.		
	Poorly designed formwork.	Ensure formwork is properly designed.		
	Offsets in formwork that restrain concrete from shrinking.	Eliminate offsets and restraint points in formwork.		
	Concrete binds on formwork during stripping.	Provide greater 'draw' on formwork and/or use improved form release agent.		
	C) Improper stripping and handling	Modify stripping and handling procedures.		

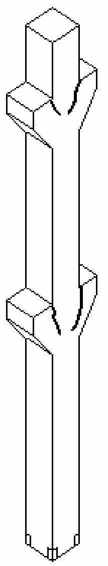
Typical case	Cause	Prevention	Effect	Repair
VERTICAL AND DIAGONAL CRACKS AT THE BOTTOM OF THE BEAM These cracks start at the bottom of the beam and extend upward. If at the end of the beam they can tend to slope diagonally upward towards the centre. It they are in the centre section of the beam they will tend to be vertical. 	**A) Improper design**		Cracks crossing strands near the end of the member can result in failure by a loss of bond between the end of the member and the crack. Transfer length is also increased. This can result in a reduction in shear capacity and failure unless sufficient shear and confinement reinforcement is provided. If no bond failure has occurred at the ends the flexural capacity is not affected. If strand slippage has occurred the capacity of the beam should be checked based on the reduced prestress. Load testing may be required to verify capacity. In some cases a reduced service load may be acceptable.	Epoxy injection can be used to restore shear capacity if there is still sufficient bonded reinforcement. Epoxy injection will not restore loss of bond or be an appropriate repair method where there is insufficient reinforcement.
	Insufficient flexural or shear capacity to carry loads.	Check design calculations for possible errors. Ensure that correct reinforcement configuration is used.		
	Prestress losses underestimated.	Reassess losses and modify stressing to suit.		
	Excessive debonding of strands at end of beam.	Ensure that sufficient strands are bonded to control cracking in this area.		
	B) Improper production			
	Incorrect placement of reinforcement.	Ensure that reinforcement is placed correctly.		
	Bond failure of strands.	Keep strands clean and ensure that concrete is properly vibrated. Ensure concrete has reach correct strength before distressing.		
	Improper strand tensioning.	Check strand extensions against calculated extensions and jack pressures. Review actual losses verses calculated losses.		
	End bearing plates restrained in form.	Modify restraint method for bearing plates.		
	Improper curing.	Improve curing methods.		
	Binding in forms.	Modify forms to prevent binding.		

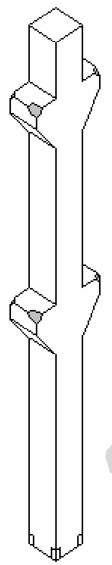
Typical case	Cause	Prevention	Effect	Repair
	Improper release.	Modify release procedures.		
	Low release strength.	Modify concrete mix design to obtain earlier design strength or delay detensioning until concrete has obtained design strength.		
	Improper procedure for detensioning.	Adopt a method that allows slow release of strands.		
	Improper detensioning sequence.	Modify detensioning sequence to ensure that prestressing force is balanced during release.		
	C) Improper storage or handling.	Modify storage and handling systems. Support beams as close to design bearing points as possible		

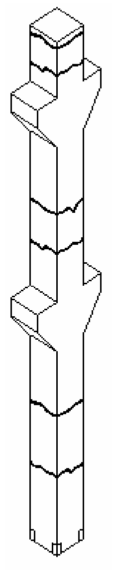
Typical case	Cause	Prevention	Effect	Repair
LEDGE CORNER CRACKS Diagonal cracks at the edge of the flange. Crack 'a' can be located anywhere along the length of the beam. Crack 'b' is usually located at the ends. 	**A) Improper production** Binding on form during stripping. Inserts fixed to form during stripping. Bearing plates not flush with formwork. Improperly debonded strands. Improper release Improper detensioning sequence. Binding on form during release.	Keep forms clean and in good repair. Use good quality release agent. Ensure that fixings for inserts are removed before stripping. Place bearing plates flush with forms and fixed in place during pouring. Modify debonding to ensure that beam does not crack. Modify release procedures. Adopt a method that allows slow release of strands. Modify form to eliminate offsets and restraint points.	Provided there is no member bearing on the ledge in the vicinity the crack is simply a cosmetic problem. Where members bear there will be a reduction in capacity particularly if reinforcement is missing or misplaced. Cracks in the bottom of the flange can reduce the bearing area or expose reinforcement but generally have little effect on capacity.	Minor cracks in non-bearing areas require only cosmetic patching. In bearing areas with adequate reinforcement the bearing area should be restored with epoxy injection or by removing loose material and patching with a propriety repair mortar. Any spalled areas should be patched to provide reinforcement cover. Where reinforcement is inadequate an auxiliary support such as a steel-bearing bracket may be required.
	B) Improper handling Edge impact during handling. Uneven supports	Protect edges during handling. Provide even supports under beam during storage.		

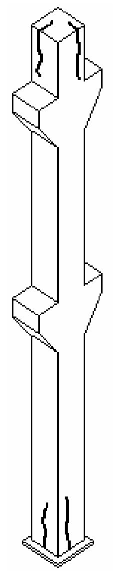
Typical case	Cause	Prevention	Effect	Repair
LEDGE CRACKS	**A) Improper production.**			
Cracks generally originate at the intersection of the web and flange and extend towards the bottom of the beam. Typically such cracks are located at the end of the beams.	Incorrect reinforcement design.	Verify the reinforcement design.	The load carrying capacity of the ledge can be significantly reduced and the effective bearing area of the beam can be affected. If reinforcement is misplaced or missing the beam capacity must be reviewed by the designer.	Where there is little load on the ledge or where there is sufficient reinforcement perpendicular to the crack epoxy injection may be used as a repair method. Where the ledge is required to support load and there is insufficient reinforcement across the crack then an auxiliary support such as a steel bracket may be used.
	Incorrect placement of reinforcement.	Ensure that reinforcement is correctly placed.		
	Inappropriate debonding of strands.	Review design of debonded strands and ensure that strands are debonded in accordance with design.		
	Improper detensioning sequence.	Modify detensioning sequence to ensure that prestressing force is balanced during release. Adopt a method that allows slow release of strands.		
	Binding on form during stripping.	Eliminate offsets and restraint points in formwork. Provide greater 'draw' on formwork and/or use improved form release agent.		

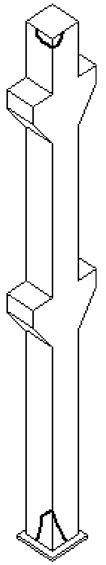
Typical case	Cause	Prevention	Effect	Repair
MISCELLANEOUS CRACKS Fine shallow cracks in the top surface of the beam occurring at random or coinciding with reinforcement. 	**A) Improper production** Surface shrinkage Rapid moisture loss. Excess water in concrete. Heat applied too early in curing cycle. Excessive curing temperatures. Settlement of concrete around top reinforcement.	Proper mix and curing. Cover concrete completely as soon as possible after pouring. Spray with curing compound or water mist before covering. Modify concrete mix design and use water reducing agents if necessary. Adjust heating cycle to slow down rate of temperature rise. Reduce curing temperatures. Allow time for initial settlement of concrete and revibrate.	Generally minor but can be serious in a corrosive environment. It there is prestressing in the top of the beam the potential for loss of bond should be assessed.	If repair is required inject cracks with epoxy or patch with a flowable grout.

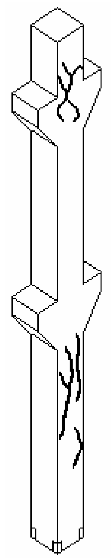
Typical case	Cause	Prevention	Effect	Repair
INTERIOR CORNER CRACK IN CORBEL Crack is located at the interior corner of the corbel and may extend at an angle into the column. 	**A) Improper design** Inadequate reinforcement to resist loads.	Review and modify the design as necessary to eliminate cracking.	Probably no effect if reinforcement is adequate and not displaced. If displacement has occurred this may not be apparent until the corbel is loaded. Cracks must be repaired if column is exposed to a corrosive environment.	Where reinforcement has not been displaced cracks may be epoxy injected. Where reinforcement is inadequate or has been displaced the column and corbel may be wrapped with bonded synthetic fibre. Alternatively the corbel can be removed and rebuilt.
	B) Improper production Reinforcement displaced during pouring. Concrete binding in forms. Improper detensioning procedures. Form expansion with curing heat.	Ensure that reinforcement is held in position during pouring. Remove corbel forms prior to detensioning. Modify detensioning procedure to maintain uniform stresses across column section. Adjust heat curing cycle.		
	C) Improper handling and storage. Incorrect support during storage. Impact during handling.	Keep support points away from corbel locations. Allow adequate clearance while handling.		

Typical case	Cause	Prevention	Effect	Repair
EXTERIOR CORNER CRACK OR SPALL IN CORBEL Crack is located at the exterior corner of the corbel and usually occurs just beyond the principal tensile reinforcement. 	**A) Improper design** Inadequate reinforcement to resist loads.	 Review and modify the design as necessary to eliminate cracking.	Probably not effect if reinforcement is not displaced. If displacement has occurred this may not be apparent until the corbel is loaded. Effect could be severe if cracks extend into bearing area. Cracks must be repaired if column is exposed to a corrosive environment.	Where reinforcement has not been displaced cracks may be epoxy injected or loose material removed and patched with a proprietary repair mortar.
	B) Improper production Reinforcement displaced during pouring. Concrete binding in forms. Improper detensioning procedures. Form expansion with curing heat.	 Ensure that reinforcement is held in position during pouring. Remove corbel forms prior to detensioning. Modify detensioning procedure to maintain uniform stresses across column section. Adjust heat curing cycle.		
	C) Improper handling and storage. Incorrect support during storage. Impact during handling.	 Keep support points away from corbel locations. Allow adequate clearance while handling.		

Typical case	Cause	Prevention	Effect	Repair
HORIZONTAL CRACK Crack is horizontal and often lines up with ligatures. Cracks may extend completely round column. 	**A) Improper production**		If crack widths are small there is no detrimental effect. Cracks must be repaired if column is exposed to a corrosive environment.	Injection with epoxy or patch with a proprietary repair mortar.
	Concrete binding on forms.	Eliminate offsets and provide adequate draw on forms.		
	Corbel restrained in forms.	Remove corbel forms prior to detensioning.		
	Form expansion with curing heat.	Adjust heat curing cycle.		
	Shrinkage	Modify mix and curing.		
	- Excess water in concrete.	Reduce water content of concrete. Consider use of high range water reducing agents.		
	- Rapid moisture loss from surface of concrete.	Apply curing covers earlier and/or mist spray exposed surfaces with water.		
	- Heat applied too early in curing cycle.	Adjust heat curing cycle.		
	- Excessive curing temperatures.	Reduce curing temperatures.		
	B) Improper handling and storage.			
	Incorrect support during storage.	Keep support points away from corbel locations and in line with lifting points.		
	Impact during handling.	Allow adequate clearance while handling.		

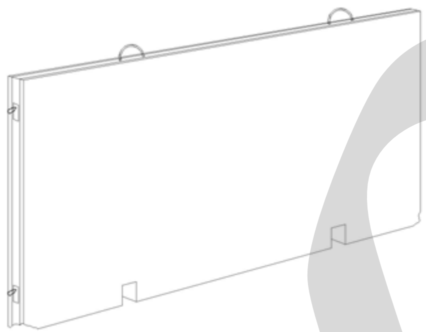
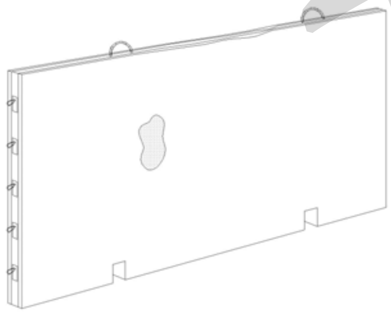
Typical case	Cause	Prevention	Effect	Repair
VERTICAL CRACK AT ENDS	**A) Improper design**		The effect will depend on the support conditions or type of connection at the base or top of column.	If sufficient reinforcement has been provided then cracks may be epoxy injected or the column wrapped with a bonded synthetic fibre.
These cracks begin at the end of the column and extend longitudinally from a few millimetres to about one metre. They are usually located in the plane of a strand.	Inadequate confinement reinforcement in anchorage zone.	Provide sufficient confining reinforcement.		
	Insufficient strand cover.	Increase strand cover.		
	**B) Improper production**			
	Concrete binding in forms.	Eliminate offsets and provide adequate draw on forms.		
	Inadequate concrete curing.	Apply curing covers to prevent heat loss at ends.		
	Improper release			
	- Improper detensioning procedure.	Adopt a method that allows slow and uniform release of strands.		
	- Strand slippage.	Ensure that strands are clean and that concrete has obtained design strength before detensioning.		

Typical case	Cause	Prevention	Effect	Repair
DIAGONAL CRACK AT ENDS	**A) Improper design**		The effect will depend on the support conditions or type of connection at the base or top of column.	If sufficient reinforcement has been provided then cracks may be epoxy injected or the column wrapped with a bonded synthetic fibre. Alternatively damaged areas can be removed and repaired.
These cracks usually occur in the corners and extend from one face to another.	Inadequate confinement reinforcement in anchorage zone.	Provide adequate confinement reinforcement.		
	Cover to main reinforcement too great.	Reduce cover to main reinforcement or provide supplementary reinforcement closer to corner.		
	B) Improper production			
	Concrete binding in forms.	Eliminate offsets and provide adequate draw on forms.		
	Stop ends binding in form during removal.	Ensure stop ends are free of concrete face.		
	Form expansion with rise in curing temperature.	Adjust heat curing cycle.		
	Improper detensioning procedure allowing column to slide in form.	Adopt a method that allows slow and uniform release of strands.		
	C) Improper handling			
	Transverse movement of column while setting it down.	Ensure column is not set down on corners or edges.		
	Impact during handling.	Allow adequate clearance while handling.		

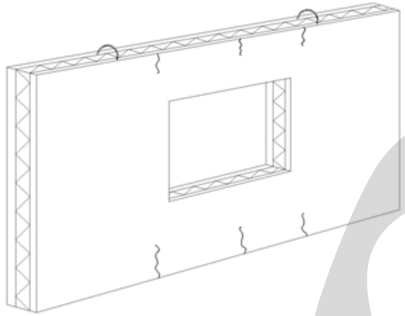
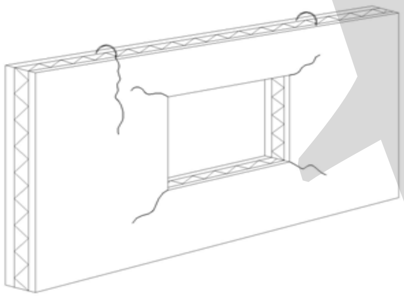
Typical case	Cause	Prevention	Effect	Repair
MISCELLANEOUS CRACKS	**A) Improper production**			
Fine shallow cracks or random pattern of intersecting coarse cracks. 	Rapid moisture loss.	Cover concrete completely as soon as possible after pouring. Spray with curing compound or water mist before covering.	Generally minor but can be serious in a corrosive environment.	If repair is required inject cracks with epoxy or patch with a flowable grout.
	Excess water in concrete.	Modify concrete mix design and use water reducing agents if necessary.		
	Heat applied too early in curing cycle.	Adjust heating cycle to slow down rate of temperature rise.		
	Excessive curing temperatures.	Reduce curing temperatures.		
	Settlement of concrete around top reinforcement.	Allow time for initial settlement of concrete and revibrate.		

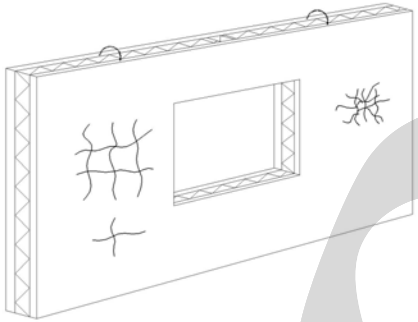
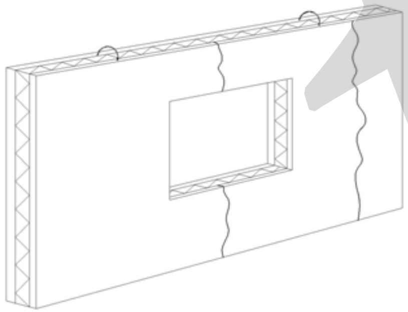
5.2 Panels

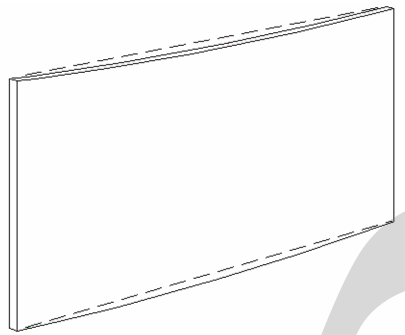
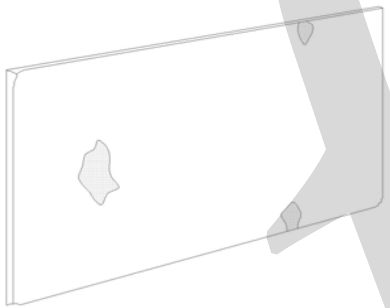
5.2.1 Load bearing panels

Typical case	Cause	Prevention	Effect	Repair
Missing dowell bars or broken corners	**A) Improper production**			
	a) Missing dowel bars or connectors failure of manufacture.	Better quality assurance.	Limitations in structural performance. Lack of connectors can prohibit the assembly.	Check of structural capability. Install of new dowel bars or new welded connectors. If repair not possible, the unit should be rejected.
	b) Broken corners failure at demould, storage or transportation.	More careful handling.	Aesthetic error. In some cases may need modification of support surfaces.	Filling with grout or screeding.
Uneven support surfaces or failures at concrete surfaces	**B) Improper production**			
	a) Uneven support surfaces pour finishing of the surface.	Better finishing.	Risk of failure at assembly.	Levelling of support surfaces with concrete of the same strength, possibly before assembly of upper structures.
	b) Failures at concrete surfaces see before.	Change vibration or mixture. Even mould surface.	No structural effect, some additional costs possible.	Plaster or screeding layer before painting.

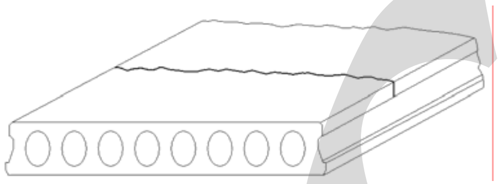
5.2.2 Non load bearing panels

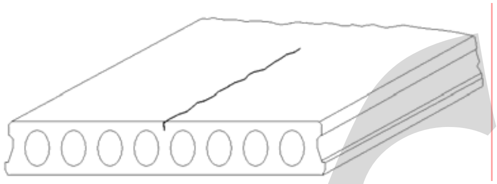
Typical case	Cause	Prevention	Effect	Repair
Cracking at panel sides 	**A) Improper production** Plastic shrinkage. Lack of edge reinforcement.	Better curing. Edge reinforcement in outer layer. Less shrinkage in concrete.	Aesthetic inconvenience, if crack width less than 0,1- 0,2 mm. Steel corrosion, if cracks wider.	Larger cracks can be injected with grout or epoxy. Surface treatment can be changed into painting or plaster.
Cracking at opening corners or lifting devices 	**A) Improper production** Cracks at openings - Quick shrinkage. - Lack of reinforcement. **B) Improper handling** Cracks at lifting devices - Too fresh concrete during handling of the unit. - False lifting device. - Too thin concrete layer.	Better curing. Less shrinkable concrete. Additional reinforcement. Concrete strength over 60% at demoulding. Tilting table moulds. Strengthening of outer layer at lifting point.	Aesthetic inconvenience, if crack width less than 0,1- 0,2 mm. Steel corrosion, if cracks wider. Concrete can be broken during lifting, if cracks wider.	Larger cracks can be injected with grout or epoxy. Surface treatment can be changed into painting or plaster. Careful erection may be possible or otherwise the unit should be rejected.

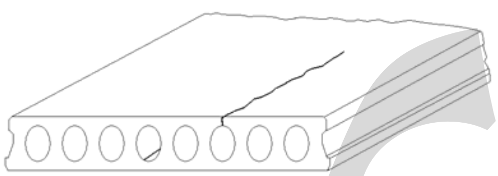
Typical case	Cause	Prevention	Effect	Repair
Surface cracking 	**A) Improper production** a) Systematic cross- ruled cracks - Separated mixture. - Too fast concrete drying. - Too small aggregate size. - Too small concrete cover of reinforcement. b) Non- systematic net- cracking - Too much cement paste. - Separated mixture. - Trowel failed. - Too high temperature gradient.	Improved cast and curing. Larger aggregate size. Check of concrete cover. Check of proportion. More exact trowel timing. Better curing.	Aesthetic inconvenience, if crack width less than 0,2 mm. Steel corrosion, if cracks wider.	Normally does not influence to other durability than frost and chemical resistance of the surface. Larger cracks can be injected with grout or epoxy. Surface treatment can be changed into painting or plaster.
Structural cracks 	**A) Improper production** a) Occurs at the age of over 1 week - Too fast heat curing. - Shrinkage of long panel prohibited (moulds for openings, steel connectors etc.). - Demoulding too early. b) Thermal deformations in the whole skeleton. This may occur during the 1st year eg. at ground or roof level.	Less heat curing and outer layer temperature less than 45ºC. Check of mould and tie bars. Demoulding strenth of concrete at least 60 %. More flexible connectors between wall panels and the skeleton.	Aesthetic inconvenience, if crack width less than 0,1- 0,2 mm. Steel corrosion, if cracks wider. Whole panel can be broken at lifting, if cracks are protruding.	If cracks protrude the panel, they should be injected or the panel should be rejected.

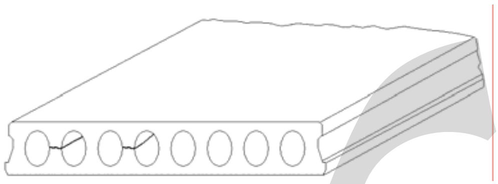
Typical case	Cause	Prevention	Effect	Repair
Bowing and other dimensional tolerances 	**A) Improper production** a) Bowing - Variations at density and shrinkage of panel layers. - Sunshine and creep at stockyard. - Long storage time. - Too long panels. b) Other dimensional tolerances - Insufficient production measures and quality control. - Long- term deformations not taken into account in design.	Avoid long storage times and sunshine for dark surfaces or long panels. Careful mixing, vibration and curing. Good measuring systems and quality control.	Influences at the visual appearance both individually and when all panels viewed together. Can limit architectural or structural performance or can make erection work impossible.	Very often panels can be drawn straight with normal or additional connectors. Panels exceeding allowed tolerances may still be acceptable, if the total erected assembly can be modified to meet structural and architectural requirements.
Surface failures and dirtyness 	**A) Improper production** a) Separation of aggregate b) Variations in colour or darkness c) Lime at surfaces **B) Improper handling** Dirt at surfaces (oil, rust,..)	Change vibration or mixture. Even mould surface, no variations at pigment amount or vibration, the same aggregate and curing all through the delivery. Careful curing and no free water on the young concrete surface. Careful production, storage and transportation.	Aesthetic problem.	a) Surface repair or rejection b) Small variations accepted. If they are larger, the panel should be rejected c) Washing with salt- phosphor- or acetic acid and water d) Washing or other cleaning

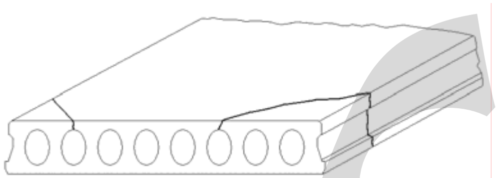
5.3 Hollow core slabs

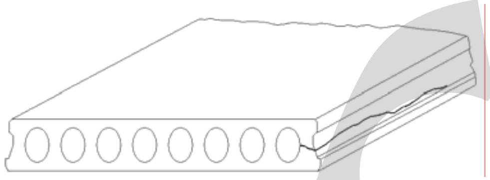
Typical case	Cause	Prevention	Effect	Repair
Transverse cracks 	**A) Improper design**. Excessive top fibre tension. Inadequate or misplaced cantilever reinforcement.	 Reduce top fibre tension. Use adequate reinforcement at proper position .	Potential shear capacity reduction if crack occurs at end. Can 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.
	B) Improper production Longitudinal shrinkage. Excessive water in concrete. Heat applied too early. Excessive curing temperature. Uneven heating along the casting bed. Contraction due to delayed detensioning of cured product. Low release strength.	 Proper mix design and curing. Reduce water content. Cover product as soon as possible after casting. Increase preset time before curing temperature rise begins. Reduce curing temperature. Check heat distribution system. Detension as soon as the release strength is reached, before the product cools. Increase release strength to accommodate top tension.		
	C) Improper handling Cantilever loading.	 Allow adequate cantilever position.		

Typical case	Cause	Prevention	Effect	Repair
Longitudinal cracks at the web 	**A) Improper production**		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.
	Subsidence over cores.	Prevent subsidence over cores.		
	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.		

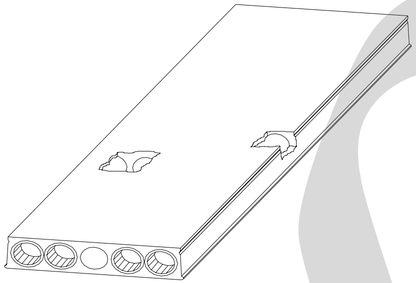
Typical case	Cause	Prevention	Effect	Repair
Longitudinal cracks over the cores 	**A) Improper design**		Cracks can affect the load distribution in slabs without concrete topping. These can also have an affect on slabs with openings or transverse cantilevers.	Filling the core solid can repair these cracks. 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 appropriate corrections.		
	Differential 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 appropriate 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	Cause	Prevention	Effect	Repair
Cracks in the web above the strand 	**A) Improper design** 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.	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 the cores where the webs are damaged.
	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.		

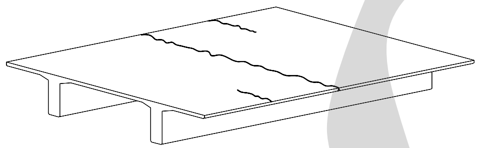
Typical case	Cause	Prevention	Effect	Repair
Cracks at corner of the member 	**A) Improper production** Saw blade pinches when member cambers. Saw cut not deep enough or wobbles due to excessive use. Excessive tension stress during stripping.	Place weight on member to restrict camber. Cut completely through the strands and as close as possible to the bottom of the member and use a properly maintained saw. Employ proper cutting sequence.	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 theses 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 corner of a member, the cracked section should be cut and rejected and the remaining length reclaimed and placed in the stock.
	B) Improper handling and storage Uneven stacking. Uneven handling to due picking devices not being level. Damage during transport.	Provide level bearing in the stack. Use spreader beams to minimise uneven handling. Ensure good transport procedures are adhered to.		

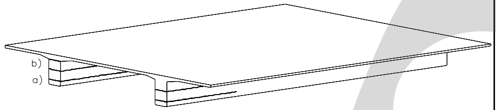
Typical case	Cause	Prevention	Effect	Repair
Longitudinal web cracks at or near the strand 	**A) Improper design** Excessive bursting stresses. Web not thick enough for prestress force. Strand diameter too large for thin web.	 Reduce bursting stresses. Increase web thickness if possible. Provide equivalent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

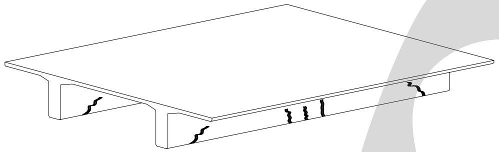
Typical case	Cause	Prevention	Effect	Repair
Accidental cracks	**A) Improper handling and storage**		Depending on their location and severity, these cracks can have significant effect on the slabs capacity. Evaluate the severity of the damage on the bending and/or the shear capacity. Work out the residual capacity of the damaged slab prior to repairs and 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.		

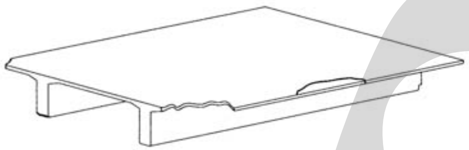
Typical case	Cause	Prevention	Effect	Repair
Imperfections in holes, recesses or lifting devices 	**A) Improper design or production**			
	Lack of digged holes or recesses.	Improved data transfer at stage of design and manufacture and improved quality control of production.	Joints cannot be finished and installations of piping cannot be done.	Recess shall be made carefully on site. Small holes are drilled and big holes cutted 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 slab increases.	Cores are plugged or ends filled with other methods before the joint cast.

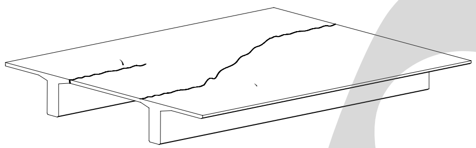
5.4 Double tee units

Typical case	Cause	Prevention	Effect	Repair
TRANSVERSAL CRACKS AT TOP FLANGE Cracks starts at the top of the unit and extends downwards through the flange and into the stem. 	**A) Improper design** Tension stress on top at midspan is too high because of bending moment caused by prestressing. Lacking or inadequate debonding of strands.	Lower prestressing and/ or add reinforcement. Add debonding of strands and /or add reinforcement in top flange.	For simply supported units the effect of cracks at midspan are minimal and they tend to close under loading. Cracks near the end of the unit can affect the shear capacity especially in a negative bending moment zone in continuous structures. Local plastic shrinkage cracking may occur on top reinforce-ment, but it has no effect on loadbearing capacity.	Minor cracks don't need any repair unless the unit will be exposed to an aggressive environment. In this case and also if the unit has cantilever loading, pressure injection with epoxy should be considered. Reinforced concrete topping repairs the cracks and gives the needed durability.
	B) Improper production False position of lifting points. Too long cantilevers. Drying shrinkage of the concrete. Expansion of the mould due to early application of heat curing. Low concrete release strength.	Ensure that lifting points are correctly located. Apply curing covers earlier and/or mist spray exposed surfaces with water. Start heat curing later. Increase concrete release strength.		
	C) Improper handling Incorrect support location at storage.	Ensure that support points are correctly located.		

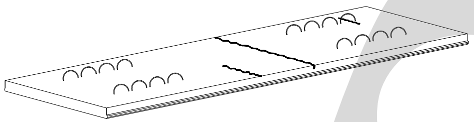
Typical case	Cause	Prevention	Effect	Repair
HORIZONTAL END CRACKS IN STEM These cracks usually begin at the end of a stem and they can extend up to about one meter. Cracks are normally horizontal at the level of a) strands or b) upper. 	**A) Improper design**		If the crack does not coincide with prestressing reinforcement the effect is minimal. The support reaction provides a clamping force that will tend to close this type of crack. If the crack coincides with prestressing reinforcement the strands can loose some or all of their bond. This can reduce the shear and flexural capacity.	If the cracks are an aesthetic harm or if the stem is exposed to a corrosive environment, epoxy injection should be considered. If the cracks may reduce structural capacity the situation should be evaluated by the designer.
	Too high prestressing force.	Respace or debond some strands at end of the beam for more even stress distribution.		
	Differential stresses between stem and flange. Excessive eccentricity of prestressing.	Add structural reinforcement. Reconfigure or debond strands for more even stress distribution.		
	Inadequate reinforcement in stem.	Add structural reinforcement.		
	Inappropriate debonding of strands together with lack of additional reinforcement.	Modify debonding configuration and/ or add structural reinforcement.		
	B) Improper production			
	Improper release of prestressing.	Use slow release of strands and modify detensioning sequence.		
	Inadequate concrete strength at release.	Modify concrete mix design as to obtain needed release strength earlier or delay detensioning.		
	Strand slippage.	Ensure that strands are clean and ensure that concrete has compacted well and reached the detensioning strength.		
	Indentations or joint offsets in forms.	Keep forms in good repair.		
	Concrete binds on mould during stripping.	Provide greater draw on mould and/ or use improved form release agent.		
	Strands are not completely cut or caught in header.	Insure that all strands are cut and allow unit to release from headers when lifting.		
	Improper end curing.	Prevent heat loss at headers.		

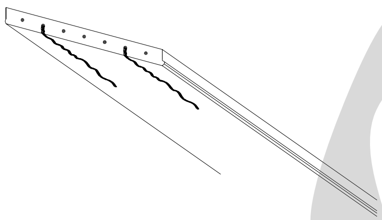
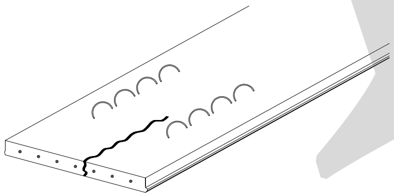
Typical case	Cause	Prevention	Effect	Repair
CRACKS AT THE BOTTOM OF A STEM Vertical cracks are usually predominant, starts from the bottom of a stem and more closely in areas of great positive moment. Diagonal cracks begin nearer the end of the stem. 	**A) Improper design** Insufficient flexural or shear capacity to carry loads. Too little prestressing. Prestress losses underestimated.	Check design calculations for possible errors. Ensure that correct reinforcement configuration is used. Reassess losses.	Cracks near the end of the unit can affect bond failure of strands. If no bond failure has occurred at ends, the flexural strength is not affected. If strand slippage has occurred, the shear and flexural capacity may have reduced.	If the cracks are due to improper production or handling, the epoxy injection can be used. If there is improper prestressing the epoxy injection will have little or no effect. The capacity based on a cracked section and reduced prestress shall be checked. Sometime also testing of the unit may be needed. A reduced service load or rejection of the slab may be considered.
	B) Improper production Bond failure at stem ends. Improper strand tensioning. Unit binding in forms.	Keep strands clean and ensure that concrete is properly vibrated. Ensure concrete has reached the detensioning strength. Check strand extensions against calculated extensions and jack pressures. Review actual losses versus calculated losses. Keep forms clean and properly oiled.		
	C) Improper handling Improper storage or handling of cantilevered units.	Lift and support cantilever units as close to bearing points as possible.		

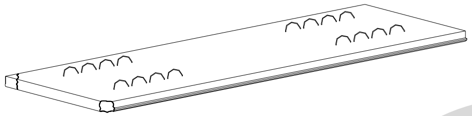
Typical case	Cause	Prevention	Effect	Repair
CRACKS AT FLANGE EDGES OR STEM CORNERS Typically cracks occur at corners or edges of the flange. 	**A) Improper design** Insufficient flange reinforcement.	Use a sufficient mesh reinforcement in proper position.	If mesh locates too near the mould, the capacity of the flange in those areas may be severely reduced. If mesh is in the proper location, these cracks will have practically no effect upon the unit's capacity unless vertical separation occurs. Cracks and block outs at the end of stem can reduce support length. The effect is however minimal if minimum support lenghts are fullfilled. Roofing adhesive can seep through and contaminate exposed areas.	If a composite concrete topping is to be applied, just provide whatever shoring is necessary to support the concrete. Minor cracks may need repair because of aesthetic reasons. If mesh is in too low position and no topping is to be used, added support for the flange must be provided. Cracks at loadbearing areas and block-outs should be repaired.
	B) Improper production Flange binding in moulds at stripping. Recesses and steel parts fixed into the mould.	Properly clean and oil edges of the mould. Ensure that recesses and steel parts are released from the mould at stripping.		
	C) Improper handling Bumbing edges or corners when handling.	Protect edges during handling, be more careful or add reinforcement.		

Typical case	Cause	Prevention	Effect	Repair
LONGITUDINAL CRACKS AT FLANGE Crack can occur at flange near the stem (a) or it can begin at one end and progress along the inside face of the stem and cross over to meet the other stem (b). 	**A) Improper design** Incomplete reinforcement in top flange (type a).	 Add transversal reinforcement (types a and b).	These types of cracks usually have no effect upon the load bearing capacity of unit. Load bearing capacity of the flange can locally be lowered. Roofing adhesive can seep through and contaminate exposed areas.	When a composite concrete topping is to be applied, no repair is needed. If no topping is used, cracks can be repaired with epoxy injection or surface treatment. If reinforcement is incomplete, the load bearing capacity must be checked.
	B) Improper production Improper and incomplete compaction of concrete. Improper order of detensioning. Improper stripping so that unit is tilted. Uneven curing or drying out. Too rapid heat curing.	 Compact concrete properly. Modify detensioning order. Use slow release of strands. Lift unit in level position so that weight is not transferred to flange. Use clean moulds. Provide greater draw on moulds. Check heat distribution system. Cover product completely and as soon as possible after casting. On extreme conditions, spray unit with curing compound before covering.		
	C) Improper handling Torsional stresses due to twisting or racking of unit. (type b) 1. during stripping 2. during handling and storage 3. during transportation	 Use handling techniques, which minimizes twist. Add transversal reinforcement at ends of the unit. Check evenness of supports at stockpiles. When rough or uneven roads must be used, keep loads light, tight the units carefully and reduce the speed.		

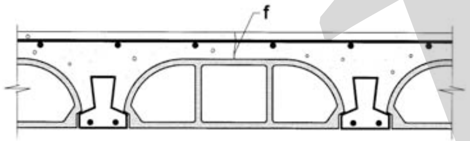
5.5 Solid planks

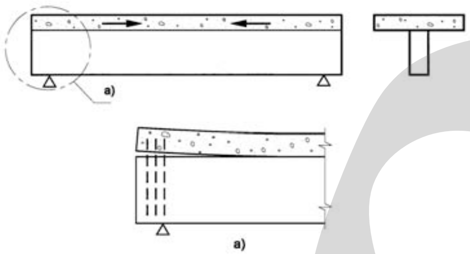
Typical case	Cause	Prevention	Effect	Repair
TRANSVERSAL CRACKS Cracks are at top surface of the plank and can reach the whole width. 	**A) Improper design** Plank has too much prestressing force.	Modify reinforcement or add thickness of plank.	Solid plank is normally part of a composite structure with topping and cracks have minor effect.	The plank must be supported by intermediate supports. If the crack goes through the depth of the plank, epoxy injection or surface treatment is needed. Concrete topping repairs the cracks.
	B) Improper production Heat curing has caused the crack before detensioning. (Eg. shrinkage crack may occur during the weekend).	Modify heat curing or concrete quality.		
	C) Improper handling Plank has been lifted too far from the middle. Lifting hooks are in a wrong position or the lifting device is not in the balance. Support blocks too far in the middle at stock piles or transportation.	Change lifting system or position of lifting hooks. Change position of support blocks.		

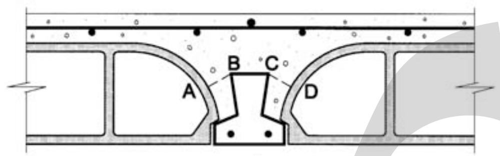
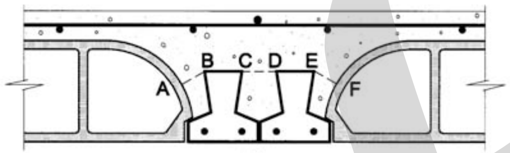
Typical case	Cause	Prevention	Effect	Repair
LONGITUDINAL CRACKS Cracks locate at the end of plank either a) in the position of or b) between prestressing strands. a)  b) 	**A) Improper design** Too big strand or prestressing force. Inadequate transversal reinforcement.	 Use smaller strands/wires or lower the force. Add reinforcement.	If there are strand slippages, loadbearing capacity has reduced.	According to quality control demands strand with slippage shall be rejected and reduced capacity of the plank is calculated.
	B) Improper production Strands too near the casting pallet. Strand slippages. Improper release of prestressing.	 Check the position of reinforcement. Use slow release of prestressing and possibly change the release order.		
	C) Improper handling Uneven or sudden lifting.	 Change lifting or improve equipment.		

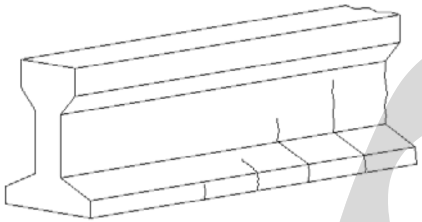
Typical case	Cause	Prevention	Effect	Repair
CRACKS AT CORNERS 	**A) Improper production** Cutting of plank is made incorrect.	Cutting order and function of a sawing machine should be checked.	No effect to load bearing capacity.	No need for repair. Block outs may need additional moulding when concrete topping is casted.
	B) Improper handling Plank has got impacts at handling or in stockyard.	More careful handling.		

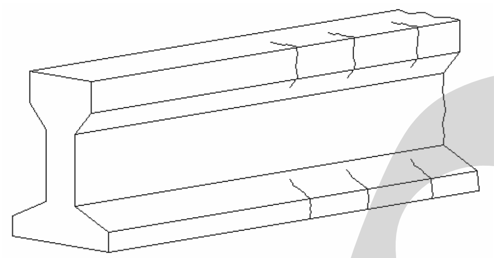
5.6 Beams and blocks

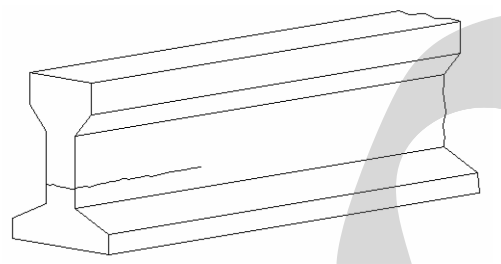
Typical case	Cause	Prevention	Effect	Repair
CRACKS DUE TO HYDRAULIC SHRINKAGE IN THE TOP OF THE SLAB 	**A) Improper construction** Excess of fines in the sand. Lack of reinforcement. Lack of curing.	Change the concrete dosage. Amount of reinforcement to prevent the defect. Better curing.	Normally cracks less than 0.2 mm width. They appear some weeks after the hardening of the concrete.	Larger cracks can be injected with grout or epoxy.

Typical case	Cause	Prevention	Effect	Repair
CRACKS OF HYDRAULIC SHRINKAGE BETWEEN IN SITU CONCRETE AND PRECAST ELEMENT 	**A) Improper design** Lack of transversal reinforcement.	Adequate transversal reinforcement.	Difficult to see in many cases. The shear capacity can be reduced.	Inject with epoxy or put mechanical connection reinforcement.
	B) Improper construction Excess of differential shrinkage of in situ concrete.	Adequate curing of in situ concrete.		

Typical case	Cause	Prevention	Effect	Repair
CRACKS DUE TO THE SHEAR AT THE INTERFACE BETWEEN IN SITU CONCRETE AND PRECAST ELEMENT  a)  b)	**A) Improper construction** Poor quality of in situ concrete. Low slump of in situ concrete. Smooth contact surface. Lack of cleaning in the prefabricated concrete surface element. Defects of striking during early age.	Better concrete quality. Use adequate concrete slump. Make rough or indented surface in the precast element. Clean the surface before concreting. Prevent settlements of props.	No visible defect. The rupture surface follows the line ABCD or ABCDEF.	Normally requires strengthening.

Typical case	Cause	Prevention	Effect	Repair
CRACKS IN THE BOTTOM FLANGE AT SERVICE LOAD 	**A) Improper design** Larger prestressing losses than calculated.	 Adequate estimation of prestressing losses.	Higher in the middle of the span. Normally appear at service load, and the crack width is less than 0.4 mm. Possible steel corrosion.	If the crack is not acceptable, inject or protect to prevent the corrosion.
	B) Improper production Stresses due to the prestressing lower than nominal value. Errors in the prestressing reinforcement position. Early transfer.	 Calibrate jacks of prestressing and elongation control of steel. Position of reinforcement. Make the transfer at the correct time.		

Typical case	Cause	Prevention	Effect	Repair
CRACKS IN ONE SIDE OF THE JOIST 	**A) Improper production** Non symmetrical position of reinforcement. Errors in the transfer.	 Position of reinforcement. Revise the procedure of transfer.	Cracks in only one side of the precast element. Irregular distribution. They appear immediately after the transfer.	Revise the load capacity of the element. Inject or protect against steel corrosion.

Typical case	Cause	Prevention	Effect	Repair
HORIZONTAL CRACKS AT THE ENDS OF THE PRECAST ELEMENT 	**A) Improper design** Excessive prestressing force in the bottom, or bad distribution of prestressing force.	Replace or change wire distribution.	If the crack does not coincide with prestressing, the affect is minimal. The end reaction tends to close this crack. If the crack coincides with prestressing reinforcement, possibility of steel corrosion. Lack of bond and reduction in flexural and shear capacity.	Inject, if necessary, for protection. If the crack reduces the structural capacity, study the safety of the general slab.
	B) Improper production Poor quality of concrete at transfer. Excess of bond between steel reinforcement and concrete.	Improve concrete quality. Use wires with smoother surface. Attention: Not possible to use transversal reinforcement to prevent the defect or to debond wires.		

6 Bibliography

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[8] Calavera, J., Rodríguez, R. *Comparación entre los niveles de seguridad de los métodos semiprobabilistas (MC-90, EC-2, EHE) y el método norteamericano ACI 318-95*. Grupo Español de IABSE. Jornadas Nuevas Técnicas de Evaluación Estructural, Rehabilitación y Refuerzo de Estructuras.

[9] Calavera, J. *Patología de estructuras de hormigón armado y pretensado*. 2nd edition. INTEMAC, 2005.

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[13] *Fabrication and Shipment Cracks in Prestressed Hollow-Core Slabs and Double Tees*. PCI Journal, January-February 1983.

[14] CIB Report No. 24, *Tolerances on Blemishes of Concrete*. CIB W-29, Rotterdam, 1973. (At the time of publication of *fib* Bulletin 41, a PDF file of this report was available for free downloading from: http://www.irb.fraunhofer.de/CIBlibrary/.)

Annex

A.1 Calculating strength capacity reduction due to a defect

Semi-probabilistic information. For the former scenario, i.e., in the event of a semi-probabilistic estimate, the load-resisting capacity requirement – in the semi-probabilistic sense – that the element should meet under nominal or design conditions is expressed symbolically in eq. (A-1). This capacity is a semi-probabilistic function of the dimensions, total area of reinforcing steel, steel strength and concrete strength and should be greater than the design strength as shown in eq. (A-1), where A is the set of all the actions to which the member is assumed to be exposed.

$$S^{n}_{R,sem} = \varphi^{n}_{sem}\left(D, A_s, \frac{f_{yk}}{\gamma_s}, \frac{f_{ck}}{\gamma_c}\right) \geq \gamma_f A \tag{A-1}$$

In practice, once a probabilistic estimate is run on the actual characteristics of the manufactured elements under investigation, eq. (A-2) is applied to calculate the semi-probabilistic load-resisting capacity under the altered conditions.

$$S^{a}_{R,sem} = \varphi^{a}_{sem}\left[D\left(1+\frac{\Delta_D}{100}\right), A_s\left(1+\frac{\Delta_A}{100}\right); \frac{f_{yk}\left(1+\frac{\Delta_s}{100}\right)}{\gamma_s}, \frac{f_{ck}\left(1+\frac{\Delta_c}{100}\right)}{\gamma_c}\right] \geq \gamma^{'}_f A \tag{A-2}$$

Each variable in eq. (A-1) is multiplied by $\left[1+\frac{\Delta}{100}\right]$, where Δ is the estimated percentage variation, semi-probabilistically speaking, of the dimensions, area of reinforcing steel, steel strength, concrete strength and so on. This formula for the semi-probabilistic load-resisting capacity under the altered conditions should be greater than any given action effects acting on the member and represented symbolically in eq. (A-2) as $\gamma^{'}_f A$. In practice strength capacity loss must be limited and required to meet the condition expressed in eq. (A-3); the recommended value of the expression k_s, which is smaller than one, will be fixed by the engineer.

$$\gamma^{'}_f \geq k_s \gamma \tag{A-3}$$

Deterministic information. Deterministic information can be obtained, for instance, if a single or a very short number of elements containing a flaw can be investigated thoroughly enough to draw reasonably certain conclusions, based on a review not only of the flaw itself but all the characteristics of the element in question, including engineering, material quality, reinforcement bar arrangement, actual final dimensions and so on. This is obviously not a case of a probabilistic estimate, but rather a situation in the understanding of the characteristics of the element is very close to being ”exact”. Consequently, there would be no point in applying additional safety coefficients such as γ_s, γ_c when computing material strength.

Under such circumstances, eq. (A-1) can be converted to eq. (A-4), which describes the deterministic load-resisting capacity under nominal or design conditions. Similarly, eq. (A-5) expresses deterministic capacity under the altered conditions.

$$S_{R,\det}^{n} = \varphi_d^n \left(D, A_s, f_{yk}, f_{ck} \right) \tag{A-4}$$

$$S_{R,\det}^{a} = \varphi_d^a \left(D\left(1+\frac{\Delta_D}{100}\right), A_s\left(1+\frac{\Delta_A}{100}\right)\right) f_{yk}\left(1+\frac{\Delta_s}{100}\right), f_{ck}\left(1+\frac{\Delta_c}{100}\right) \tag{A-5}$$

The criterion on which the acceptance or otherwise of the element is based is expressed by eq. (A-6), analogous to eq. (A-3), although the value of k_d is not the same as the value of k_s in eq. (A-3), as discussed in the recommendations set out below.

$$S_{R,\det}^{a} \geq k_d S_{R,\det}^{n} \tag{A-6}$$

A.2 Maximum allowable strength loss

There are no hard and fast rules about the maximum value of strength reduction, i.e., the minimum values of k_s and k_d in eq. (A-3) and (A-6). Table A-1, however, adapted from a similar table in (9), contains recommended values for both semi-probabilistic and deterministic scenarios.

$$k_s = 1 - \frac{\lambda_s}{100} \qquad\qquad k_d = 1 - \frac{\lambda_d}{100}$$

Type of information		Semi-probabilistic λ_s	Deterministic λ_d
Base value (%)		9	12
Review of structural engineering	Limited (%)	0,3	0,4
	Full (%)	1	1,3
Material testing	Limited (%)	0,3	0,4
	Intense (%)	1	1,3
Review of construction	Limited (%)	0,2	0,3
	Intense (%)	0,5	0,7
Importance of member failure in the structure as a whole	Slight (%)	1,2	1,7
	High (%)	0,4	0,5
Probability of occurrence of actions	Low (%)	0,5	0,6
	High (%)	0,1	0,2
Level of safety to live load	Low (%)	0,1	0,2
	High (%)	0,5	0,6
Warning	No cracking or deformation (%)	0	0
	Cracking or deformation (%)	0,4	0,6
	Cracking and deformation (%)	0,8	1,5
Reliable collaboration from non-structural parts	Negligible (%)	0	0
	Substantial (%)	0,5	0,7
TOTAL LIMIT		15	20

Table A-1: Recommendations for establishing reinforcement limits (expressed in per cent of strength reduction) [1]

[1] The limit value is obtained by adding the values of all relevant columns to the base value.

A.3 Examples

Example 1

Assume the precast element whose section is specified in the figure below.

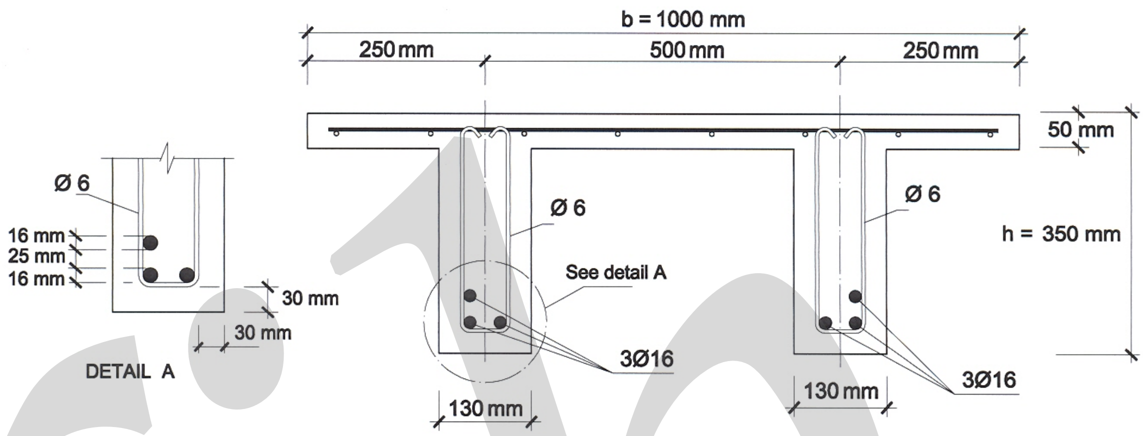


Figure A-1: Definition of a precast element

The properties and partial safety factors of the materials used are:

Concrete	C-30 (Cylindrical specimen, 15/30)
Steel	B 500

$\gamma_c = 1{,}5$

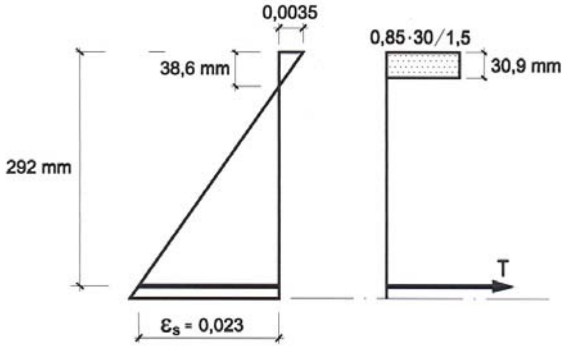
$\gamma_s = 1{,}15$

In routine statistical control of the concrete conducted during the manufacture of 320 identical elements, the strength found was $f_{c,est} = 21MPa$ i.e., 30% lower than the strength specified.

Study the loss in flexural strength.

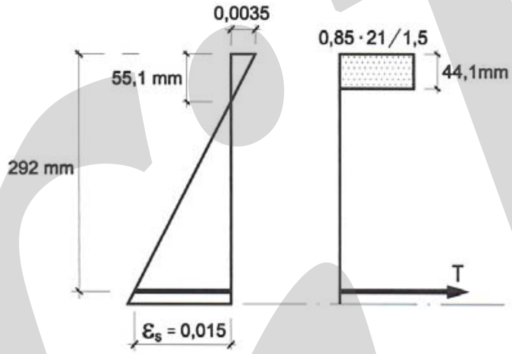
a) This calls for a **semiprobabilistic** approach.

Design conditions would be as follows:



$$0.023 > \frac{500/1.15}{200.000} \quad M_{u,n} = 145.05\,mkN$$

and the altered conditions as shown below:

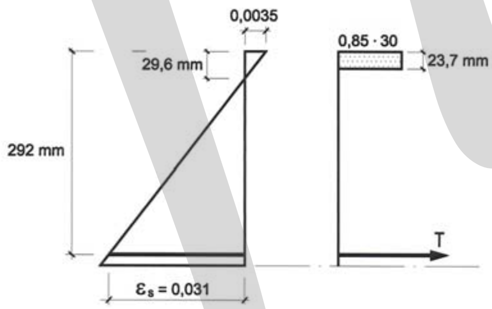


$$0.015 > \frac{500/1.15}{200.000} \quad M_{u,a} = 141.77\,mkN$$

$$VR = 100 \cdot \frac{141.77 - 145.05}{145.05} = -2.39\%$$

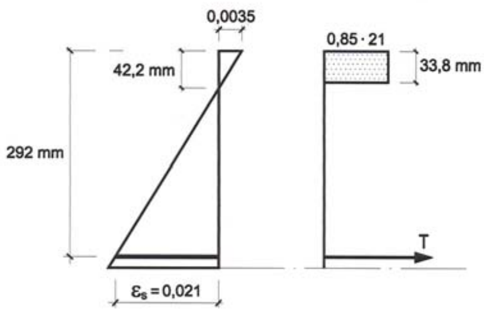
If the information had mistakenly been taken to be deterministic, the results would be:

For design conditions:



$$0.031 > \frac{500}{200.000} \quad M_{R,n} = 169.19\,mkN$$

For altered conditions:



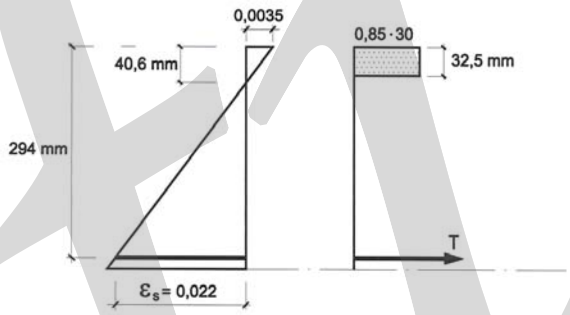
$$0.021 > \frac{500}{200.000} \qquad M_{R,a} = 166.4\,mkN$$

$$VR = 100 \cdot \frac{166.4 - 169.19}{169.19} = -1.81\%$$

Example 2

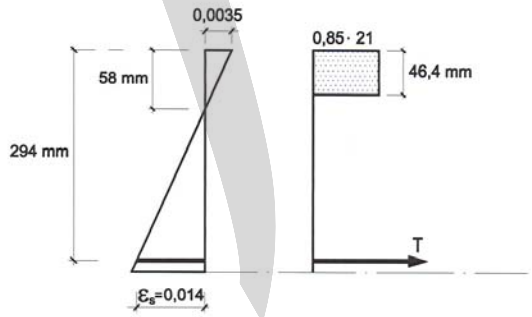
Assume the same element as in Example 1, but reinforced with 4Ø20 + 2Ø16 The flaw was found to affect only two elements. The reinforcement control tests, element dimensions and cover were reviewed. Sample specimens were taken of the two elements. The information, therefore, is deterministic.

a) Under design conditions:



$$0.022 > \frac{500}{200.000} \qquad M_{R,n} = 230\,mkN$$

Under altered conditions:

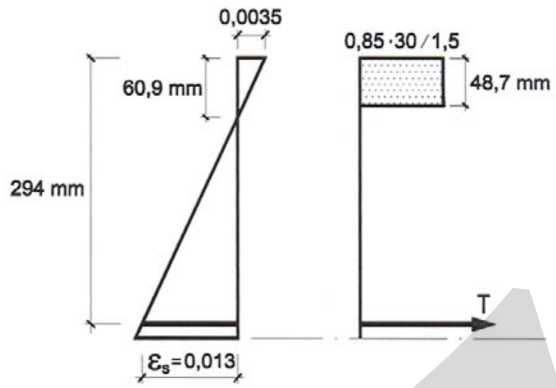


$$0.014 > \frac{500}{200.000} \qquad M_{R,a} = 224.2mkN$$

$$VR = 100 \cdot \frac{224.2 - 230}{230} = -2.5\%$$

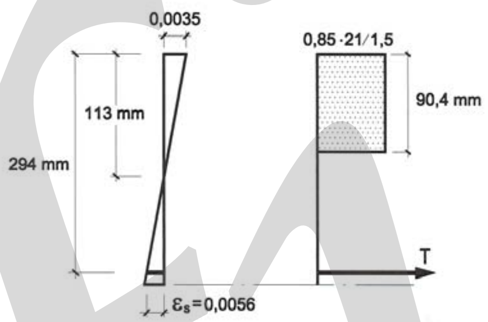
If the information had mistakenly been taken to be semiprobabilistic, the results would be:

For design conditions:



$$0.013 > \frac{500/1{,}5}{200.000} \qquad M_{u,n} = 223.3\,mkN$$

For altered conditions:



$$0.0056 > \frac{500/1{,}5}{200.000} \qquad M_{u,a} = 179.1\,mkN$$

$$VR = 100 \cdot \frac{179.1 - 223.3}{223.3} = -19.8\%$$

Remarks on examples 1 and 2:

- In Example 1, the variations in strength, VR (-2.39% and –1.81%), are practically the same regardless of whether the information is taken to be semiprobabilstic or deterministic, because under either of the two approaches, the compression block is always within the 50 mm depth of uper slab.

- Where a higher steel ratio is used, however, such as in Example 2, the deterministic method leads to VR = -2.5% and the semiprobabilstic calculation to an appreciably larger VR = -19.8%. This is due to the fact that, under the altered conditions, contrary to the findings of the deterministic analysis, with the semiprobablistic approach the compression block overruns substantial areas of the ribs.