भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
BUREAU OF INDIAN STANDARDS
(Ministry of Consumer Affairs, Food & Public Distribution, Govt. of India)

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व्यापक परिचालन मसौदा

हमारा संदर्भ: सीईडी 46/टी-12 **27 मार्च 2025**

तकनीकी समिति: भारत की राष्ट्रीय भवन निर्माण विषय समिति, सीईडी 46

प्राप्तकर्ता :

1. सिविल अभियांत्रिकी विभाग परिषद, सीईडीसी के सभी सदस्य
2. राष्ट्रीय भवन निर्माण संहिता विषय समिति, सीईडी 46 के सभी सदस्य
3. सीईडी 46 की उपसीमितयों और अन्य कार्यदल के सभी सदस्य
4. रुचि रखने वाले अन्य निकाय।

महोदय/महोदया,

निम्नलिखित मानक का मसौदा संलग्न हैं:

प्रलेख संख्या	शीर्षक
सीईडी 46 (27021) WC	**भारत की राष्ट्रीय भवन निर्माण संहिता भाग 6 संरचनात्मक डिजाइन अनुभाग 7 पूर्व संविरचन, सिस्टम भवन तथा मिश्रित/संमिश्र निर्माण** [SP7(भाग 6 अनुभाग 7) का चौथा पुनरीक्षण] (आई सी एस नंबर: 01.120: 91.040.01)

कृपया इस मसौदे का अवलोकन करें और अपनी सम्मतियाँ यह बताते हुए भेजे कि यह मसौदा प्रकाशित हो तो इस पर अमल करने में आपको व्यवसाय अथवा कारोबार में क्या कठिनाइयां आ सकती हैं।

सम्मतियाँ भेजने की अंतिम तिथि: 30 अप्रैल 2025

सम्मति यदि कोई हो तो कृपया अधोहस्ताक्षरी को ई-मेल द्वारा ced46@bis.gov.in पर या उपरलिखित पते पर, संलग्न फोर्मेट में भेजें। सम्मतियाँ बीआईएस ई-गवर्नेंस पोर्टल, www.manakonline.in के माध्यम से ऑनलाइन भी भेजी जा सकती हैं।

यदि कोई सम्मति प्राप्त नहीं होती है अथवा सम्मति में केवल भाषा संबंधी त्रुटि हुई तो उपरोक्त प्रलेख को यथावत अंतिम रूप दे दिया जाएगा। यदि सम्मति तकनीकी प्रकृति की हुई तो विषय समिति के अध्यक्ष के परामर्श से अथवा उनकी इच्छा पर आगे की कार्यवाही के लिए विषय समिति को भेजे जाने के बाद प्रलेख को अंतिम रूप दे दिया जाएगा।

यह प्रलेख भारतीय मानक ब्यूरो की वैबसाइट www.bis.gov.in पर भी उपलब्ध हैं।
धन्यवाद।

भवदीय

ह/-
(द्वैपायन भद्र)
वैज्ञानिक 'ई' एवं प्रमुख (सिविल अभियांत्रिकी विभाग)

सलंग्न: उपरिलिखि

भारतीय मानक ब्यूरो
(उपभोक्ता मामले, खाद्य एवं सार्वजनिक वितरण मंत्रालय, भारत सरकार)
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WIDE CIRCULATION DRAFT

Our Reference: CED 46/T-12 **27 March 2025**

National Building Code of India Sectional Committee, CED 46

ADDRESSED TO:

1. All Members of Civil Engineering Division Council, CEDC
2. All Members of the National Building Code Sectional Committee, CED 46
3. All Members of Subcommittees, Panels and Working Groups under CED 46
4. All other interests

Dear Sir/Madam,

Please find enclosed the following draft:

Doc No.	Title
CED 46 (27021) WC	**National Building Code of India Part 6 Structural Design Section 7 Prefabrication Systems Building and Mixed Composite Construction** [Fourth Revision of SP 7 (Part 6 Section 7)] (ICS No. 01.120: 91.040.01)

Kindly examine the attached draft and forward your views stating any difficulties which you are likely to experience in your business or profession, if this is finally adopted as National Standard.

Last Date for comments: 30 April 2025

Comments if any, may please be made in the enclosed format and emailed at **ced46@bis.gov.in** or sent at the above address. Additionally, comments may be sent online through the BIS e-governance portal, **www.manakonline.in**.

In case no comments are received or comments received are of editorial nature, kindly permit us to presume your approval for the above document as finalized. However, in case comments, technical in nature are received, then it may be finalized either in consultation with the Chairman, Sectional Committee or referred to the Sectional Committee for further necessary action if so desired by the Chairman, Sectional Committee.

The document is also hosted on BIS website **www.bis.gov.in**.

Thanking you,

Yours faithfully,

Sd/-
(Dwaipayan Bhadra)
Scientist 'E' / Director and Head
(Civil Engineering Department)

Encl: As above

FORMAT FOR SENDING COMMENTS ON THE DOCUMENT

[Please use A4 size sheet of paper only and type within fields indicated. Comments on each clause/sub-clause/ table/figure, etc, be stated on a fresh row. Information/comments should include reasons for comments, technical references and suggestions for modified wordings of the clause. **Comments through e-mail to ced46@bis.gov.in shall be appreciated**.

Doc. No.: CED 46 (27021) WC **BIS Letter Ref**: CED 46/T-12

Title: National Building Code of India Part 6 Structural Design Section 7 Prefabrication Systems Building and Mixed Composite Construction [Fourth Revision of SP 7 (Part 6 Section 7)] (ICS No.01.120:91.040.01)

Last date of comments: **30 April 2025**

Name of the Commentator/ Organization: ________________________________

Clause/ Para/ Table/ Figure No. commented	Comments/Modified Wordings	Justification of Proposed Change

NOTE- Kindly insert more rows as necessary for each clause/table, etc

BUREAU OF INDIAN STANDARDS

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Draft Indian Standard

National Building Code of India

PART 6 STRUCTURAL DESIGN

Section 7 Prefabrication Systems Building and Mixed Composite Construction

[Fourth Revision of SP 7 (Part 6/Section 7)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46	**Last Date for Comments: 30 April 2025**

C O N T E N T S

National Building Code Sectional Committee, CED 46

FOREWORD

This Code (Part 6/Section 7) gives recommendations regarding modular planning, component sizes, prefabrication systems, design considerations, joints and manufacture, storage, transport and erection of prefabricated concrete elements for use in buildings and such related requirements for prefabricated concrete.

Prefabrication, though desirable for large scale building activities, is now gaining importance for use in the country. Two aspects of prefabrication, specifically to be borne in mind, are the system to be adopted for the different categories of buildings and the sizes of their components. Here the principle of modular coordination is of value and its use is recommended.

Advantages of recent trends in prefabrication have been taken note of and also the hazards attended to such construction. Some of the essential requirements for the manufacture of the prefabricated components and elements are also included in this Subsection.

Since the aim of prefabrication is to effect economy and improve quality and speed of construction, the selection of proper materials for prefabrication is also an important factor in the popularization of this technique. The use of locally available materials with required characteristics and the materials which, due to their innate characteristics such as lightweight, easy workability, thermal insulation, non-combustibility, etc, that effect economy and improve quality, may also be tried. However, this Subsection pertains to prefabricated elements with cementitious materials.

The design of prefabricated buildings shall include provision for installations of all services and required piping, wiring and accessories to be installed in the building.

This Section was first published in 1970 and was subsequently revised in 1983, 2005 and 2016. In the first revision in 1983, the main changes made included: inclusion of brief provision regarding importance of architectural treatment and finishes as applicable to prefabricated buildings; addition of a brief clause on the requirements of materials for use in prefabrication; elaboration of the clause on prefabricating systems and structural elements; revision of the clause on testing of components to include testing of structure or part of structure; and addition of a brief clause on the manufacture of cellular concrete.

In the second revision in 2005, this Section 7, earlier named as 'Prefabrication and Systems Building' was renamed and restructured as follows:

Section 7 Prefabrication, systems buildings and mixed/composite construction
7A Prefabricated concrete

7B Systems buildings and mixed/composite construction

In the second revision in 2005, several significant changes were introduced to enhance the standard. The modular coordination and modular dimensions of components were revised to allow greater flexibility in planning. Provisions related to tolerances were updated to address various types of prefabricated components. Additionally, a detailed clause on design requirements was incorporated to ensure the safety of prefabricated buildings against progressive collapse. Furthermore, a new clause specifying the sampling procedure for testing components was added.

In the third revision in 2016, in the Subsections 7A and 7B, several significant modifications had been incorporated. Definitions for new terms have been added, and existing terminologies have been modified where necessary. Provisions related to prefabricated systems have been updated, and detailed guidelines on the diaphragm action of floor systems have been included. The emulative system has been categorized and elaborated on, covering its definition, analysis, design, and detailing. Design considerations have been revised to account for accidental impacts due to vehicles. Provisions and testing procedures for the water tightness of joints have been introduced, along with illustrations of typical precast joint details. Fire resistance testing of prototypes under sustained loads has been addressed, and reliance solely on frictional resistance for connections between adjacent prefabricated members has been replaced with recommendations for resistance using shear. Updates have also been made to provisions on site prefabrication and vertical stacking guidelines, including restrictions on the number of components stacked on the ground. The time duration for load testing selected components from a lot has been modified. Additionally, new provisions for tolerances during erection and associated design considerations have been added. An annex has been included to address common defects, their causes, and remedies, covering issues such as dimensional deviations, cracks, honeycombing, damages, strand slippage, and alignment problems.

In this revision, it has been decided to merge subsections 7A and 7B into Section 7, ‘Prefabrication, Systems Buildings, and Mixed/Composite Construction’. The following major modifications have been incorporated in this revision:

a) Definitions of some new terms have been added and existing terminologies modified, wherever required.

b) Provisions relating to prefab systems namely moment resisting frame system, braced frame system, load bearing wall system, cell system and hybrid system are given along with its types and their applications.

c) Emulative system has been categorized and detailed with respect to its definition, analysis, design, detailing, etc.

d) Provisions relating to the design of corbel, bearing including dapped bearing are given in detail.

e) Provisions relating to quality control and assurance have been included.

g) Provisions for tolerances in erection and associated design considerations have been updated.

h) Provisions and testing procedures for water tightness of joints have been included.

j) A guideline for 3D printed concrete structures has been included in Annex A.

k) A comprehensive guideline on prefabricated prefinished volumetric construction (PPVC) methods, materials, design standards, and performance criteria for building professionals and stakeholders involved in modular construction has been included at Annex B.

m) Guidelines for design for manufacturing and assembly has been included in Annex C.

n) Annex D on common precast connection has been modified based on the current practices in precast industry.

p) Sustainability in precast concrete construction has been included in Annex F.

This information contained in this section is largely based on IS 15916:20xx, 'Building Design and Erection Using Prefabricated Concrete – Code of Practice (*second revision*)' (*under preparation*).

All standards, whether given herein above or cross-referred to in the main text of this Subsection, are subject to revision. The parties to agreement based on this Subsection are encouraged to investigate the possibility of applying the most recent editions of the standards.

For the purpose of deciding whether a particular requirement of this Subsection is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Subsection.

Important Explanatory Note for Users of the Code

In any Part/Section of this Code, where reference is made to **'good practice'** in relation to design, constructional procedures or other related information, and where reference is made to **"accepted standard"** in relation to material specification, testing, or other related information, the Indian Standards listed at the end of the Part/Section shall be used as a guide to the interpretation.

At the time of publication, the editions indicated in the standards were valid. All standards are subject to revision and parties to agreements based on any Part/ Section are encouraged to investigate the possibility of applying the most recent editions of the standards.

In the list of standards given at the end of a Part/Section, the number appearing within parentheses in the first column indicates the number of the reference of the standard in the Part/Section. For example:

a) Good practices [6-6A(1)] refers to the Indian Standard(s) give at serial number (1) of the list of standards given at the end of this Part/Section, that is, IS 13920 : 2016 'Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (first revision)'

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Draft Indian Standard

National Building Code of India

PART 6 STRUCTURAL DESIGN

Section 7 Prefabrication Systems Building and Mixed Composite Construction

[Fourth Revision of SP 7 (Part 6/Section 7)]

(ICS No. 01.120: 91.040.01)

National Building Code Sectional Committee, CED 46	Last Date for Comments: 30 April 2025

1 SCOPE

1.1 This Code (Part 6/Section 7) gives recommendations regarding prefabrication systems, design considerations, component sizes joints and manufacture, storage, transportation and erection of prefabricated concrete elements for use in buildings and such related requirements for prefabricated concrete.

1.2 For the scope of this code, only emulative detailing approach is covered where the precast elements are connected at site using wet concrete or grout pour with reinforcement detailing as per the relevant design codes. It should be noted that the design and detailing requirements of good practice [6-7(1)] are stipulated specifically for CIS concrete. However, the design engineer should aim for achieving similar detailing requirements in members or elements. Precast technology requires discretized element for construction, hence may not always allow for achieving the same method of detailing at the joints. In such instances, the requirements noted in this section as appropriate should be adopted. In cases where, this section is silent but a modified detailing that proves performance of the structure in terms of strength, stiffness and ductility, the design engineer may adopt the same with mutually agreed by the design team and approved by the authority.

2 TERMINOLOGY

For the purpose of this Section, the following definitions shall apply.

2.1 Authority Having Jurisdiction – The authority which has been created by a statute and which, for the purpose of administering the code/part, may authorize a committee or an official or an agency to act on its behalf; hereinafter called the 'authority'.

2.2 Basic Module – The fundamental module used in modular coordination, the size of which is selected for general application to building and its components.

NOTE — The value of the basic module has been chosen as 50 mm for the maximum flexibility and convenience. The symbol for the basic module is *M*.

2.3 Cellular Concrete – The material consisting of an inorganic binder (such as lime or cement or both) in combination with a finely ground material containing siliceous material (such as sand), gas generating material (for example, aluminium powder), water and harmless additives (optional); and/or steam cured under high pressure in autoclaves.

2.4 Components – A building product formed as a distinct unit having specified sizes in three dimensions.

2.5 Composite Members – Structural members comprising prefabricated structural units of steel, prestressed concrete or reinforced concrete and cast *in-situ* concrete connected together in such a manner that they act monolithically.

2.6 Diaphragm – It is a horizontal or nearly horizontal structural system (for example, reinforced concrete floors and horizontal bracing systems), which transmits lateral forces to vertical elements that resist earthquake-induced inertia effects.

2.7 Increments – Difference between two homologous dimensions of components of successive sizes.

2.8 Light-Weight Concrete – Concrete of substantially lower unit weight (1 400 kg/m^3 to 1 800 kg/m^3) than that made from gravel or crushed stone.

2.9 Module – a unit of size used in dimensional coordination.

2.10 Modular Coordination – dimensional coordination employing the basic module or a multimodule.

NOTE – The purposes of modular co-ordination are,

a) to reduce the variety of component sizes produced, and

b) to allow the building designer greater flexibility in the arrangement of components.

2.11 Modular Grid – a rectangular coordinate reference system in which the distance between consecutive lines is the basic module or a multimodule. This multimodule may differ for each of the two dimensions of the grid.

2.12 Multimodule – a module whose size is a selected multiple of the basic module.

2.13 Prefabricate – to fabricate concrete components or assembled units prior to erection or installation in a building.

2.14 Prefabricated Building – the partly/fully assembled and erected building, of which the structural parts consist of prefabricated individual units or assemblies using ordinary or controlled materials, including service facilities; and in which the service equipment may be either prefabricated or constructed *in-situ*.

2.15 Sandwich Concrete Panels – panels made by sandwiching an insulation material between two layers of reinforced/prestressed concrete to act as insulation for composite or non-composite concrete panels.

2.16 Self Compacting Concrete – concrete that is able to flow (650 mm in diameter) under its own weight and completely fill the voids within the formwork, even in the presence of dense reinforcement without any vibration, whilst maintaining homogeneity without segregation.

2.17 Shear Connectors – structural elements, such as anchors, studs, channels, loops and spirals, intended to transmit the shear between the prefabricated member and the cast *in-situ* concrete and also to prevent separation at the interface (to transmit the interfacial shear).

2.18 System – it is a particular method of construction of buildings with certain order and discipline using the prefabricated components which are inter-related in functions and are produced based on a set of instructions.

2.19 Unit – building component formed as a simple article with all three dimensions specified, complete in itself but intended to be part of a larger, compound unit or complete building. Examples are brick, block, floor panel, wall panel, and other individual components.

2.20 Emulative Detailing System – a connection detailing system for precast concrete structures that has structural performance equivalent to that of a conventionally designed, cast *in-situ*, monolithic concrete structure

2.21 Jointed Detailing System – a connection detailing system for precast concrete structures that has individual precast components separated from each other but connected using special connections such as welded or bolted plates.

2.22 Terminology Relating to 3D Printing

2.22.1 *Extrusion-based concrete 3D printing* – Extrusion based printing refers to the delivery of the concrete through a nozzle in the required shape and dimension, in a layer-by-layer deposition process. The nozzle can either be placed on a gantry or attached to a central robot or a rail mounted mechanism.

2.22.2 *Binder Jetting-based 3D printing* – Binder jetting is a 3D printing technology in which a liquid binding agent (water) is sprayed on the surface of a thin layer of the binder (cement and aggregate) to attain the required shape and dimensions. A new layer of the binder is then placed on the top of the existing layer, and the process of spraying the water is repeated. The process is continued until reaching the required height of the object. The formed object is allowed to harden before removing the excess unreacted binder.

2.22.3 *Print plane* – The plane on which the material is deposited.

2.22.4 *Directions in the printed specimens* – The performance of the printed specimen varies with the principal directions of the printed concrete. The directions of the printed concrete are designated as X, Y and Z with reference to the print pathway.

a) X direction is parallel to the print direction and in the print plane
b) Y direction is perpendicular to the print direction in the print plane and could cross different layers
c) Z direction is perpendicular to the print direction and print plane, crossing many printed layers

2.22.5 *Concrete for 3D Printing* – Concrete is a composite material with cement (ordinary Portland cement blended with or without supplementary cementitious materials), water, fine aggregate, coarse aggregate and admixtures. Fine aggregates and coarse aggregate need to comply with the requirements of accepted standard [6-7(58)]. Aggregates can be used in the mix subjected to testing and validation, confirming to the required printable properties like pumpability, buildability and extrudability.

2.22.6 *Printable Concrete* – Printable concrete is a mixture of cement (with or without supplementary cementitious materials), water, aggregates and admixtures that can be extruded through the nozzle of the printer and attain the designed dimension within certain tolerance zone on placing additional layers.

2.22.7 *Buildability* – Buildability is the ability of the printed layers to develop adequate green strength to withstand the self-weight as well as load due to subsequent layers without significant geometrical deformation or collapse of the freshly printed component.

2.22.8 *Extrudability* – Extrudability is the ability of the mixture to pass through the nozzle under pressure and attain the designed shape after the extrusion.

2.22.9 *Pumpability* – Pumpability is the ease of transporting concrete mixture from the pump to the nozzle.

2.22.10 *Printability* – The printability of the mixture is a combination of the pumpability and extrudability.

2.22.11 *Open time* – Open time represents the time over which the 3D printing mixture remains printable. This defines the time period in which the mixture can be delivered through the pumping system and dispensed through the nozzle without clogging of the extrusion system.

2.22.12 *Filament* – The extruded shape is termed as the filament. The cross section of the filament can be circular, rectangular, or square, depending on the shape of the nozzle. The filament is characterised by its diameter (for circular nozzle) or by its orthogonal dimensions – width and thickness. However, it can be of any shape.

2.22.13 *Layer* – A layer is the object formed with a single pass of the printer. Multiple layers are stacked one over the other to build up the full object. Each layer is characterized by the height or thickness, for rectangular or square nozzles.

2.22.14 *Bond* – Bond is an interface between successive layers or filaments of a 3D printed concrete specimen. The interface between layers can be called as ‘horizontal’ bond, while the interface between filaments side by side can be called as ‘vertical’ bond.

2.22.15 *Shape Stability* – Shape stability is the ability of the printed component to maintain the dimension as subsequent layers are placed.

2.22.16 *Base Layer* – A base layer is the first printed layer on which all following layers are built on.
2.22.17 *Dead Zone Length* – The dead zone length is defined as the length of static deposition of concrete or where the material flow stops such as near the nozzle with rapid change in cross section.

2.22.18 *Extracted Specimen* – Specimen of the required dimension which is extracted (cored/sawn) from the 3D printed concrete elements in any orientation.

2.22.19 *Speed of Extrusion (Extrusion Speed)* – The rate at which the extrusion system moves while extruding the concrete. Generally expressed in length/ unit time, volume/ unit time, or mass/ unit time.

2.22.20 *Admixtures (Including Superplasticizer and Accelerator)* – Superplasticizers are required in 3D printed mixes in order to control the workability of concrete and make it suitable for pumping and extrusion. Accelerators are admixtures added to the concrete to decrease the initial setting time and increase the early-age strength.

2.22.21 *Viscosity Modifier* – An admixture that when added to the concrete, modifies the viscosity of the mix.

2.22.22 *Out-of-Plane Deformation* – Distortion/bending of the printed layers from the predefined (vertical) plane of the specimen. Intentional cantilevering or offset shall be allowed and is not considered as out-of-plane deformation.

3 MATERIALS

The relevant materials for precast structures shall satisfy the requirements given in the following sections. For sustainability aspects, see **F-2** and **F-5**.

3.1 Concrete Ingredients

3.1.1 *Cement*

The cements shall be selected in accordance with good practice [6-7(2), (3)] to provide predictable strength and durability, in addition to consistent colour. Each shipment of cement shall be referenced to a certified mill test report that indicates compliance with the specified type of cement.

3.1.2 *Mineral Admixtures*

Mineral admixtures, if specified by the contract or the design, the provisions of good practice [6-7(3)] shall apply.

3.1.3 *Aggregates*

Aggregates used in concrete shall comply with accepted standard [6-7(4)]. All aggregates must be sourced from approved suppliers, with representative samples tested according to the requirements specified in the governing standards. The desired concrete properties must be demonstrated through trial mixes to ensure compliance and satisfactory performance.

The provisions of good practice of [6-7(2)] shall apply while deciding the maximum and minimum size of coarse aggregate.

For thin sections, the maximum size of aggregate shall be limited to 10 mm with fines 12 percent or less.

3.1.4 *Water*

Water used for concrete mixtures shall conform to good practice [6-7(3)]. In addition, mixing water shall be free from deleterious matter that may interfere with the setting or strength development of the concrete. Water shall be tested based on the batching requirements at least once a month for high quality assurance.

3.1.5 *Chemical Admixtures*

3.1.5.1 All chemical admixtures such as accelerating admixtures, retarding admixtures, water-reducing admixtures, air-entraining admixtures and superplasticizing admixtures shall comply with accepted standards [6-7(5)].

3.1.5.2 Admixtures containing chloride ions shall not be used.

3.1.5.3 Admixtures must be checked for compatibility with cement and other admixtures to ensure proper performance. A trial mix program shall evaluate slump, stability, workability, air content, and strength under typical precast concrete conditions, including temperature and humidity. The effect of dosage variations and admixture addition order shall be determined from supplier recommendations or trial.

3.1.5.4 Synthetic or natural pigments may be used in precast facade or decorative elements to achieve desired colours. The pigments must be insoluble in water, free of soluble salts, acids, and calcium sulphate, and resistant to sunlight, alkalis, and weak acids. The pigment type and amount must not affect concrete setting or strength.

3.2 Concrete Mix Design

Qualification of a concrete mix for use in precast concrete production shall be through laboratory testing, production trials and quality control testing. The minimum grades of concrete shall be as per good practice [6-7(2) and (3)].

3.2.1 *Mix Development*

3.2.1.1 Concrete mixes for precast elements shall be determined through laboratory methods, complying with good practice [6-7(3)] exposure class requirements. The mix shall meet project needs, service conditions, and desired surface finish (colour and texture), with adequate workability for proper placement and consolidation. Water use shall be minimized to the amount necessary for proper placing and vibration consolidation.

3.2.1.2 For standard concrete, the mix design procedure shall be as per accepted standards [6-7(6) and (3)] shall be used for the correlation between compressive strength and tensile strength, modulus of elasticity, shrinkage, creep coefficient, co-efficient of thermal expansion, etc.

3.2.1.3 Special concretes (for example, high-performance, ultra-high-performance, self-compacting) shall be designed based on specialized literature and approved by the competent authority. This literature shall also correlate compressive strength with other properties such as tensile strength, modulus of elasticity, shrinkage, creep, and thermal expansion.

3.2.1.4 Steel fibre reinforced concrete, specified in structural elements to enhance mechanical and durability properties, shall be designed using hooked, crimped or straight steel fibres as per specialized literature and appropriate approvals from competent authority. Any construction joint in precast steel fibre reinforced concrete elements shall have rebar across the joint to transfer stresses.

3.2.1.5 Lightweight concrete shall be used for non-structural precast elements (such as wall panels, facade units, and sandwich panels) to reduce the self-weight, enhance ease of handling and transportation, thermal insulation, and sound absorption. For lightweight concrete, adjustments are required during mix design to account for the lower density and altered workability. Specialized literature shall be referred and appropriate approvals from competent authority shall be obtained.

3.2.2 *Miscellaneous*

3.2.2.1 All the concrete mixes to be used in the production of precast elements shall be evaluated as trial batches, prepared in accordance with accepted standard [6-7(7)]. under conditions that simulate the actual production and finishing as closely as possible.

3.2.2.2 If the brand of cement, source/gradation of aggregates or brand of admixture are changed after mix finalization, the proportions of the mix shall be validated and re-designed, if required.

3.2.2.3 When accelerated curing is to be used, the mix proportions shall be based on similarly cured test specimens.

3.2.2.4 When self-compacting concrete is used, the mix proportion shall meet the requirement of accepted standards [6-7(8)].

3.3 Reinforcement

3.3.1 Reinforcing bars and prestressing strands shall be specified in accordance with the provisions of good practice [6-7(2) and (3)], respectively. Reinforcing steel deliveries shall be identified with a heat number that can be correlated with a mill certificate.

3.3.2 For welding of reinforcement, if needed, relevant clauses of accepted standards [6-7(9)] shall be referred.

3.3.3 Reinforcement couplers shall comply with the relevant clauses of accepted standard [6-7(10)].

3.3.4 If glass fibre reinforced polymer bars are used, the material shall conform to the requirement of accepted standard [6-7(11)].

3.3.5 Welded wire reinforcement shall conform to the requirements of accepted standard [6-7(12)].

3.3.6 Welding shall not be performed near any prestressing strand, whether tensioned or not tensioned. The prestressing strand shall not be exposed to spatter, direct heat, or short-circuited current flow.

3.3.7 Prestressing accessories shall comply with the requirements of good practice [6-7(13)].

3.3.8 Plastics for welded wire and bar supports shall be composed of polyethylene, styrene copolymer rubber-resin blends, polyvinyl chlorides and polytetrafluoroethylene. Plastics shall be alkali-resistant and have thermal properties compatible with concrete.

3.4 Grout

3.4.1 *Cementitious Grout*

3.4.1.1 Cementitious grout used in the precast application shall be as per good practice [6-7(2) and (3)].

3.4.1.2 Non-shrink non-metallic high-strength and flowable grouts shall be used for all structural joints. The grout strength shall exceed the strength of the joining member by at least 5 MPa. If the strength of the members varies, the grout with the highest required strength shall be used.

3.4.1.3 For joint width more than the technical specifications of grout material or 100 mm, the grout shall be mixed with 10 mm down aggregate.

3.4.2 *Chemical Grouts*

Chemical grouts shall be used as per manufacturer’s guidelines and its properties shall comply with accepted standard [6-7(14)].

3.5 Mould

3.5.1 All moulds, regardless of material, shall conform to the profiles, dimensions, and tolerances of precast concrete product indicated by the contract documents and the approved shop drawings.

3.5.2 Repeated use of moulds shall not cause any dimensional or planar changes that exceed allowable tolerances of the member. Mould materials must not exceed tolerance limits due to warping or buckling, even when exposed to temperature fluctuations or moisture.

3.5.3 Moulds exposed to external vibrations must be capable of transmitting these vibrations evenly across a sufficient area, without flexing, warping, or causing plate flutter.

3.5.4 If it is planned to apply a prestressing force by jacking against the mould, the mould shall be sufficiently strong to withstand the force without buckling or wrinkling and still maintain the required dimensional tolerances.

3.5.5 When different materials are used to construct the mould, they shall not affect the colour and texture of the precast concrete product. The mould materials shall be non-absorbent or properly sealed to prevent excessive moisture absorption to minimize variations in finish.

3.5.6 Wooden moulds shall be sealed with suitable materials to prevent moisture absorption.

3.5.7 Steel moulds shall be visually inspected before each use for rust, distortion, and tightness of steel sheet joints.

3.5.8 Fibre reinforced polymer moulds shall be used for achieving localized architectural finishes.

3.5.9 Moulds shall be coated with mould release agents that will permit release without damaging or staining the concrete, and without affecting subsequent coating, painting, or caulking operations. Debonding agents or wax shall be used during match casting.

3.5.10 Whenever concrete is to be painted or stained, only mould release agents compatible with the coating shall be permitted, unless surface preparation is performed to ensure good adhesion between the coating/stain and the concrete.

3.6 Hardware, Lifting Devices and Miscellaneous Materials

3.6.1 *Hardware*

3.6.1.1 Hardware refers to items (a) to be placed on or in the structure to receive the precast concrete units (anchor bolts, angles, or plates with suitable anchors), (b) to be embedded in the concrete units for connection or for other mechanical, plumbing, glazing, miscellaneous iron, masonry, roofing works, etc., and (c) necessary for the installation of the precast concrete units.

3.6.1.2 Hardware shall be made from ductile materials or as specified in the design. Plates and angles should be low-carbon steel, and anchor steel should match the strength of the anchored material. Brittle materials, like high-carbon steels or gray iron, should be avoided. For high-strength materials, the design must ensure elastic behaviour. For testing, **10** shall be referred.

3.6.1.3 Welding of steel plates, angles, and other shapes shall be carried out by certified welders in conformance with the standard procedures. The size, length, type, and location of all welds shall conform to those shown on the shop drawings, and no unspecified welds shall be added without approval of the site engineer/designer.

3.6.1.4 Electrodes used for welding operations shall be bought in sealed (airtight) containers. The selection of a suitable electrode shall be made based on the material to be welded, intricacies based on the geometry of the job, thickness, weld profile and weld position. The maintenance of any electrode used shall be as prescribed by the manufacturer.

3.6.1.5 All metallic hardware surfaces that are exposed to or within 12 mm of concrete surfaces that are exposed to the weather, corrosive conditions, or condensation shall be protected against corrosion or be made of non-corrosive materials. Hardware shall be properly cleaned before application of protective treatment. Corrosion protection shall be done as required. Care shall be taken to prevent chemicals, such as acids, from contacting the hardware and causing corrosion.

3.6.2 Supplier of hardware shall furnish records of compliance to specification requirements and mill certificates for the material used. Review of hardware fabrication shall be performed by quality control personnel.

3.6.3 *Lifting Devices*

3.6.3.1 Lifting devices shall be capable of supporting the element in all positions planned during manufacture, storage, delivery, and erection. Safe loads for lifting inserts or hooks or devices shall be supplied by the manufacturer of proprietary devices. Information on the use and installation of the devices to ensure proper performance shall be supplied by the manufacturer. For factor of safety and capacity of lifting inserts or hooks, **5** and **6** shall be referred, respectively. For testing, **10** shall be referred.

3.6.3.2 If the lifting device is subjected to dynamic loads, it shall preferably be fabricated using ductile materials or shall be designed to remain elastic.

3.6.3.3 Reinforcing bars shall be avoided for lifting hooks in multiple handling applications. If smooth bars are required for lifting, a known steel grade bar bent to correct size and shape shall be used, provided adequate embedment or mechanical anchorage exists.

3.6.3.4 Each bar size and configuration shall be considered such that it meets load and handling requirements.

3.6.3.5 Coil rods and bolts shall not be welded when used in lifting operations.

3.6.3.6 Connection hardware shall not be used for lifting or handling unless carefully reviewed and approved by the site engineer/designer.

3.6.3.7 Shop drawings shall clearly define insert dimensions and locations for fabrication and placement or refer to standard details.

3.6.3.8 Corrosion protection shall be considered when such hardware is stored.

3.6.4 *Surface Finishes and Coating*

3.6.4.1 All surface finishes and coating on precast concrete units shall be as stated in the shop drawing.

3.6.4.2 When specified in the project requirements, finishing processes such as sandblasting, acid etching, surface retardation, the use of mould liners, or the application of veneer facing materials may be employed to achieve the desired surface appearance. These methods shall help control form joints, form blemishes, and air voids within acceptable limits.

3.6.4.3 Curing compounds for precast elements shall be chosen for compatibility with coatings, moisture retention, and ease of removal. Only membrane-forming compounds that meet standards for water retention and curing efficiency shall be used. Application should occur immediately after demoulding to prevent moisture loss and ensure proper strength. The surface must be free of dust or laitance, and curing must be uniform to avoid streaking. Curing compounds must be non-residual or removable when subsequent coatings are applied.

3.6.4.4 Anti-carbonation coatings shall be selected for CO_2 diffusion resistance, breathability, and UV stability, conforming to durability standards. They must be tested for permeability and adhesion on precast surfaces. Application should occur on clean, dry, fully cured concrete, free from laitance, dust, and form oil. Coatings must be applied evenly to avoid streaks and ensure effective protection.

3.6.4.5 Paints used on precast elements shall be alkali-resistant, weatherproof, and compatible with the concrete substrate. Selection shall be based on exposure conditions, including moisture, UV, and chemical resistance requirements. Before application, the surface must be properly primed, and any efflorescence or moisture-related defects must be addressed to prevent peeling or discoloration. Roller or spray application shall ensure uniform coverage, and multiple coats shall be applied as required to achieve the desired opacity and aesthetic consistency.

3.6.4.6 Epoxy coatings, selected for chemical resistance, adhesion, impact resistance, and fire rating, are used for flooring, structural connections, and corrosion protection. Surfaces must be clean and dry, with a primer applied for better bonding. Curing conditions should be controlled, and components must be mixed correctly and applied evenly to avoid uneven gloss or discoloration.

3.6.4.7 PU or hybrid sealants for external precast joints must be compatible with concrete, offer high elongation (for grouted joint 25 percent or more, for non-grouted joints 200 percent or more), and resist UV and environmental degradation. Selection should consider joint movement, exposure, and adhesion. Joints must be clean, dry, and free of contaminants before application, with a primer used if needed. Proper tooling is essential to ensure seamless finishes and prevent air pockets. Sealants in grouted joints act as moisture barriers, so their lifespan must be verified.

3.6.5 *Insulation Material*

3.6.5.1 Rigid foam insulation for precast elements shall be selected based on thermal resistance, compressive strength, and moisture resistance. Expanded polystyrene, extruded polystyrene, polyurethane or polyisocyanurate etc., are preferred for long-term efficiency. Panels must conform to accepted standard [6-7(15)] or relevant manufacturer guidelines for density, strength, and thermal conductivity. Panels shall be precisely cut for a snug fit to minimize thermal bridging. Exposed foam surfaces must be protected with coatings for durability and UV resistance. Foam with strength more than 10 MPa or as per design may be used in flooring to reduce concrete weight and thickness.

3.6.5.2 Mineral wool insulation shall be selected for its fire resistance, acoustic properties, and vapour permeability. Rigid or semi-rigid panels shall be used to withstand the casting process without compression. Mineral wool products conforming to accepted standard [6-7(16)] or any relevant manufacturer's guidelines shall possess thermal conductivity, density, moisture absorption, and fire resistance requirements. Before placement, mineral wool boards shall be dry, securely positioned, and properly supported to prevent displacement when concrete is poured. Special care shall be taken to prevent fibre shedding, which can affect worker safety and surface finish. If exposed, mineral wool shall be coated or encased to prevent moisture absorption and fibre degradation over time.

3.6.5.3 Lightweight concrete used for insulation layers in precast elements shall be selected based on its density, thermal performance, and compatibility with structural concrete. Autoclaved aerated concrete and non-autoclaved cellular concrete conforming to accepted standard [6-7(17)] shall be used or any relevant manufacturer's guidelines shall be followed. Proper mix design and curing conditions shall be maintained to achieve uniform density and minimize shrinkage or cracking. During production, the interface between lightweight and normal concrete layers shall be well bonded to prevent delamination. Surface smoothness and uniformity shall be checked, as inconsistencies may affect finishing and overall insulation performance.

3.7 Connections

In addition to the requirements in **3.6.1**, the materials of a connection shall be selected such that embrittlement of any part of the assembled connection will not occur. Non-ferrous inserts shall be resistant to electrolytic action and alkali attack. Documentation shall be provided showing satisfactory results over a reasonable period of time. If more than one material is used in a connection, abutting materials shall be selected such that corrosion is not induced. Dissimilar metals shall not be embedded near or in direct contact in moist or saturated concrete unless detrimental chemical or electrochemical (galvanic) reactions are ensured not to occur. For testing, **10** shall be referred.

3.7.1 *Wire Loop System - Loop Box*

3.7.1.1 The wire loop system (proprietary product) is a load-transferring, cast-in element consisting of a box and a U-shaped wire loop for connecting prefabricated concrete elements. Generally, the joint with wire loop boxes is considered non-structural and should only be used for durability requirements.

3.7.1.2 Relevant manufacturer's guidelines shall be used for selecting the appropriate product. In addition to that, the following points shall be considered.

3.7.1.3 The box and the two flexible wire loops shall be made of carbon steel sheet and high strength wire ropes, respectively. The surface of the box shall be equipped with a profiled surface to ensure sufficient bonding with the surrounding concrete.

3.7.1.4 Proper selection involves ensuring compliance with tensile strength requirements and alignment accuracy to prevent misfits. High-strength, non-shrink grout is recommended to encapsulate loops fully. Care shall be taken in application to maintain uniform joint appearance, especially in exposed architectural elements.

3.7.1.5 The looped wire ropes shall not react with grout and form corrosion. Also, shall not be used if found having corrosion.

3.7.1.6 The manufacturer shall furnish the detailed technical datasheet along with the test results corroborating the values noted in the technical datasheet. Also, the same shall be verified by the engineer in charge by conducting appropriate testing per batch.

3.7.2 *Grouted Coupler*

3.7.2.1 Grouted couplers (proprietary product) provide mechanical splicing of rebars between precast elements, ensuring structural continuity.

3.7.2.2 Selection shall consider compatibility with rebar sizes and compliance with applicable standards.

3.7.2.3 Rebar ends and coupler interiors shall be clean before grouting to ensure proper bonding. A high-performance grout, characterized by non-shrink non-metallic high strength properties, high early strength, and durability, shall be used to ensure effective load transfer. The grout shall meet the specified compressive strength and flowability requirements for complete void filling. Adequate curing time shall be allowed for strength development. Misalignment or incomplete grouting shall be addressed through inspection to maintain both functionality and appearance.

3.7.2.4 Type 2 coupler shall be used with appropriate testing as per **10**.

3.7.3 *Terminators (Headed Bars)*

3.7.3.1 Headed bars are used in precast concrete elements to enhance anchorage efficiency by providing an enlarged head at the end of the reinforcement bar, reducing the required development length.

3.7.3.2 These bars shall be manufactured from high-strength reinforcement steel to ensure adequate ductility and mechanical performance. The heads shall be formed through welding, forging, or mechanical attachment and shall comply with the specified geometric and strength requirements. The selection of headed bars shall be based on design specifications, including bar grade, head dimensions, and load transfer capacity.

3.7.4 *Metal Inserts*

3.7.4.1 Steel plates shall be cast into precast elements to facilitate connections with other structural components. Plates shall be made from structural-grade steel with appropriate thickness, positioned accurately during casting, and securely anchored to prevent displacement.

3.7.4.2 Welded studs shall provide reliable load transfer by creating strong mechanical bonds between steel inserts and concrete. Studs shall be manufactured from high-strength steel and shall conform to applicable material and welding standards. Proper fusion and alignment shall be ensured, and weld quality shall be verified through inspection to prevent structural deficiencies.

3.7.4.3 Corrosion protection, such as galvanization or stainless-steel alternatives, shall be applied based on environmental exposure conditions. Protective measures shall not interfere with mechanical performance or bonding with concrete. In exposed applications, surface finishes shall be considered to maintain aesthetic quality.

3.7.5 *Shims*

3.7.5.1 Plastic shims shall be made from materials with adequate compressive strength (minimum 10 MPa or as per design requirements), and resistance to moisture and UV degradation. The selection of plastic shims must ensure durability and reliable performance under temperature fluctuations. Shims shall be free from defects, warping, and shall be sized to fit the required gap accurately.

3.7.5.2 Metal shims shall be used in applications requiring wider gap (40 mm or larger), higher strength and load-bearing capacity, particularly where greater stability and structural support are needed. For shims thicker than 40 mm, tack welding shall be performed between the layers to ensure a strong bond and prevent shifting or separation of the individual layers. Metal shims that are exposed to the environment or are in contact with moisture or corrosive elements shall be provided with appropriate corrosion protection. Care must be taken during installation to ensure that the corrosion protection is intact and not compromised by any mechanical processes.

4 PRECAST CONCRETE SYSTEMS

4.1 General

Compared to CIS construction, precast concrete system requires the following additional considerations such as, types of components, appropriate connection, integrity of the members, degree of flexibility and constraint. Depending on the choice of the design engineer, the major connections between the elements are designed & constructed as pinned joints or rigid or ductile depending on seismic load consideration. The horizontal elements (slabs, staircases, beams) are all simply supported or converted to be continuous. Provisions of in-situ structural topping/ screed, integrity ties and collector elements ensure the diaphragm action to distribute the lateral load to the LLRS (lateral load resisting system) depending on the choice of design engineer. Vertical elements (walls and columns) may be designed as continuous. If not part of LLRS, the connections between the beam and column may be designed as pinned, to transfer the gravity loads with appropriate displacement compatibility. However, distribution of minor column moments arising from eccentric beam reaction shall be considered. Such frames shall be appropriately braced using beams or structural wall. The following clauses shall be referred for selection of precast concrete system.

4.2 System Considerations

4.2.1 *Structural Concept*

In comparison to cast-in-place construction, conscious effort shall be made in precast construction to ensure structural continuity between the elements and the overall system. The selected system shall be robust and shall be designed to achieve the following:

a) Stability against progressive collapse
b) Structural Failure
c) Cracking
d) Unacceptable deformation

4.2.1.1 The stability of system as a whole and its part thereof shall be ensured at all stages during the erection, and service life. The following factors shall be considered for the selection of precast system:

a) Grid distances
b) Spanning direction of slab and beam
c) Position of columns and walls
d) Position of load bearing walls and/or facade and/or facade at stilt
e) Position and approximate requirements for stabilizing elements
f) Position of expansion joints

4.2.1.2 The type of Precast Concrete System shall be chosen as per Table 1.

Table 1 Applications of Types of Precast Concrete Systems
(*Clause* 4.2.1.2)

Sl No.	Systems		Types	Application: Functionality	Application: Height of Structure m	Application: Earthquake Zone	Application: Response Reduction Factor
(1)	(2)		(3)	(4)	(5)	(6)	(7)
i)	Moment Resisting Frames	a	System A1	Industrial sheds, Warehouses, Single storey dwellings with mezzanine	12	All	2
		b	System A2,A3, A4 (OMRF)	Car Parking, Schools, Retail and Shopping complex, Office, Data Centres	15	I, II and III	2
			System A2,A3, A4 (SMRF)		35	All	4
		c	System B1 (OMRF)		15	I, II and III	2.5
			System B2 (SMRF)		35	All	4.5
		d	System C1, C2, C3 (OMRF)		15	I, II and III	3
			System C1, C2, C3 (SMRF)		35	All	5
ii)	Braced Frames	a	Precast frame (Type A/B/C) OMRF with ordinary cast-in-situ core	Schools, Hospitals, Hostels, Commercial complex, Offices, Data Centres	–	I, II and III	3
		b	Precast frame (Type A/B/C) OMRF with ordinary cast-in-situ core		–	I, II and III	3.5
		c	Precast frame (Type A/B/C) OMRF with ductile cast-in-situ core		–	All	4
		d	Precast frame (Type A/B/C) SMRF with ductile cast-in-situ core		–	All	4.5
		e	Precast frame (Type A/B/C) OMRF with jointed cast-in-situ core		70	I, II and III	2.5
		f	Precast frame (Type A/B/C) SMRF with jointed cast-in-situ core		70	I, II and III	3
		g	Precast frame (Type A/B/C) OMRF with monolithic cast-in-situ core		–	I, II and III	4
		h	Precast frame (Type A/B/C)		–	All	5

Sl No.	Systems		Types	Application			
				Functionality	Height of Structure m	Earthquake Zone	Response Reduction Factor
(1)	(2)		(3)	(4)	(5)	(6)	(7)
			SMRF with monolithic cast-in-situ core				
iii)	Wall Systems	a	Ordinary Jointed system	Residential and housing	70	I, II and III	2.5
		b	Ductile Jointed system		90	All	3
		c	Ordinary Monolithic system		70	All	3
		d	Ductile Monolithic system		–	All	4
		e	Non-jointed system		15	I and II	2
iv)	Cell system	a	Ordinary Monolithic system	Residential and housing	70	All	3
		b	Ductile Monolithic system		–	All	4
v)	Hybrid System		SMRF PRESS	Car Parking, Commercial complex	–	All	5

NOTES

1 Ordinary jointed – When shear stress at joints is greater than 1.3 MPa, under ultimate loads.

2 Ductile jointed – When shear stress at joints is less than 1.3 MPa, under ultimate loads.

3 For mixed systems, response reduction factor is governed by vertical system considered.

4.2.2 *Standardization of Precast Components/Elements*

The precast components/elements shall preferably be standardized based on the structural, architectural and/or aesthetic requirements. The precast components/elements given below and not limited to shall be used in accordance with relevant Indian Standards (*see* Part 5 'Building Materials' of the Code) and the accepted standards, where available:

a) Reinforced/prestressed concrete channel unit,
b) Reinforced/prestressed concrete slab unit,
c) Reinforced/prestressed concrete beams,
d) Reinforced/prestressed concrete columns,
e) Reinforced/prestressed concrete hollow core slab,
f) Reinforced concrete waffle slab/shells,
g) Reinforced/prestressed concrete wall elements,
h) Hollow/solid concrete blocks and battens,
j) Precast planks and joists for flooring and roofing,
k) Precast joists and trussed girders,
m) Light weight/cellular concrete slabs/wall panels,
n) Precast lintel and *Chajjas*,
p) Large panel prefabricates,
q) Reinforced/prestressed concrete trusses,
r) Reinforced/prestressed roof purlins,

s) Precast concrete L-panel unit,
t) Prefabricated concrete double-T unit,
u) Prefabricated brick panel unit,
v) Prefabricated sandwich concrete panels,
w) Precast concrete foundation, and
y) Precast concrete staircase.

4.2.2.1 Any other types of components shall be used with approval of the Competent Authority and appropriate testing.

4.3 Basic Precast Concrete Systems

Precast concrete building systems are composed of some basic types of structural systems. These systems shall be combined in various ways to obtain a suitable and effective structural concept that meets the needs of specific buildings. The most common systems are:

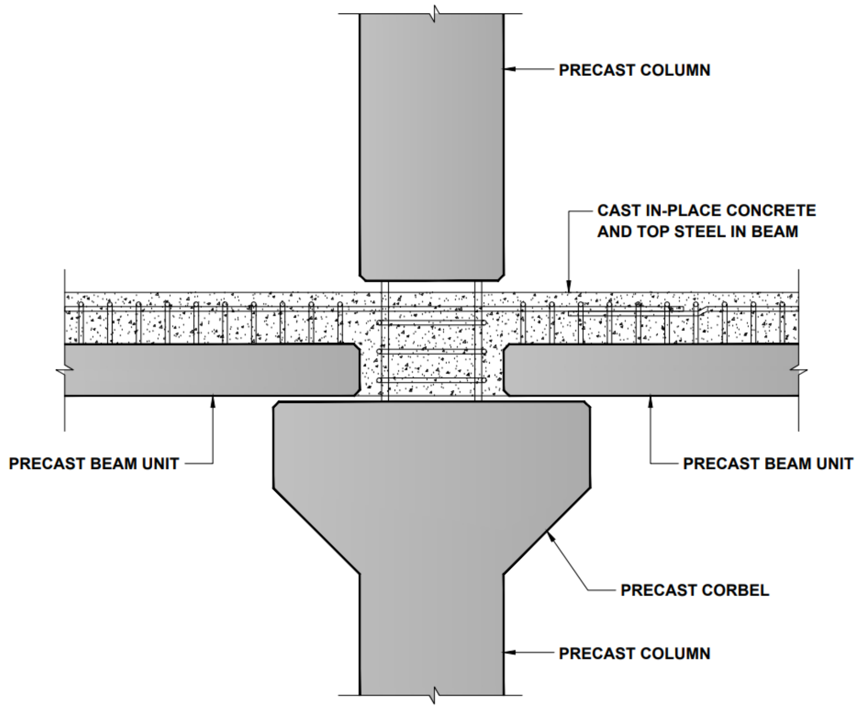
a) Moment resisting frame system
b) Braced frame system
c) Load bearing wall system
d) Cell system
e) Hybrid system

4.3.1 The above list is not unique as there are many permutations possible to achieve the same objectives, such as the use of arches, and rigid portal frames.

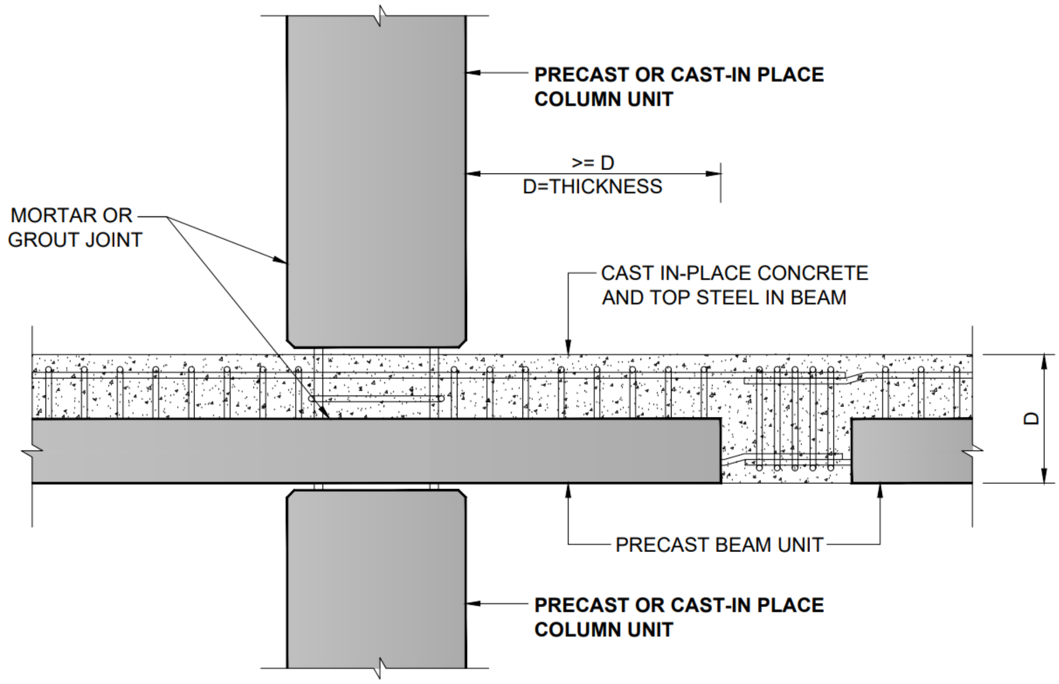
4.3.2 Facades systems if used as load-bearing wall, the lateral stability of wall shall be considered in design. For non-structural facade elements, movement of beam shall be accounted in the connection between the facade and beam, to avoid cracking of facade element.

4.3.3 Choice of Type A, Type B or Type C, as shown in Fig. 1, depends on the importance of building and the level of ductility required. The connection shown can be designed to act fixed or pinned depending on the framing and detailing requirements.

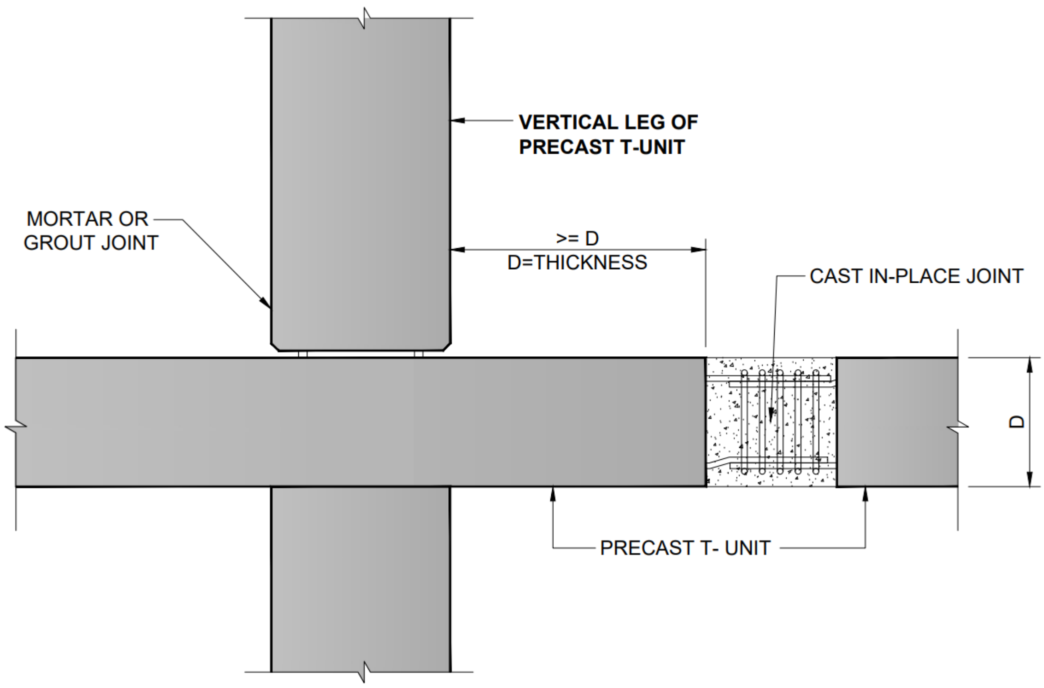
4.3.4 Partial fixity offered by the pin connections due to topping slab or dowels may be considered for serviceability checks by considering an effective flexural rigidity (EI) considering the effect of topping.


PRECAST COLUMN
CAST IN-PLACE CONCRETE
AND TOP STEEL IN BEAM
PRECAST BEAM UNIT
PRECAST BEAM UNIT
PRECAST CORBEL
PRECAST COLUMN

TYPE A


PRECAST OR CAST-IN PLACE
COLUMN UNIT
>= D
D=THICKNESS
MORTAR OR
GROUT JOINT
CAST IN-PLACE CONCRETE
AND TOP STEEL IN BEAM
D
PRECAST BEAM UNIT
PRECAST OR CAST-IN PLACE
COLUMN UNIT

TYPE B



TYPE C

FIG. 1 PRECAST BEAM-COLUMN CONNECTION

4.3.5 *Skeletal Frame Systems*

Beam-column systems or skeletal frame systems shall be adopted for commercial buildings, schools, hospitals, parking structures, sporting facilities, industrial structures, warehouses, etc, where a high degree of flexibility in planning and arrangement of floor areas can be achieved using large spans. Skeletal frame systems shall be any of the following types:

a) Moment resisting frames
b) Braced frames with stabilizing cores (with precast structural walls)
c) With core and moment frame

4.3.5.1 *Moment resisting frames*

For lateral load resistance, rigid beam-column connection shall be achieved using any of following types. Type A, Type B or Type C depends on the importance of building and the level of ductility required. Structural topping shall be provided for achieving diaphragm action as per minimum thickness guidelines presented in **4.3.7.1**.

a) *Type-A frames* – Type A frames shall consist of precast beam units between columns/column corbels, where columns can be cast-in-place or precast (*see* Fig. 2). These shall be achieved by adopting either one or a combination of the following arrangements:

1) System A1 – Moment connection for the cantilevered columns shall be adopted at the base with pin ended (hinged) beam-column connections. Slab units shall be simply supported.

2) System A2 – Column shall be fixed at base and spliced at each floor level along with provision of temporary or permanent corbels. Depending on design requirements, beams shall be designed as simply supported for temporary loading and made continuous for permanent loading. Slab units shall be simply supported.

3) System A3 – Columns shall be 1 and 2 or 2 and 3 storeys high with staggered joints and, fixed at base and beam levels. Staggering of columns shall be provided such that only 50 percent of all columns are spliced at each storey level. Depending on design requirements, beams shall be designed as simply supported for temporary loading and made continuous for permanent loading. Slab units shall be simply supported.

4) System A4 – Columns shall be 3 or 4 storeys high with corbels and fixed at the base. Depending on design requirements, beams shall be designed as simply supported for temporary loading and made continuous for permanent loading. Slab units shall be simply supported.

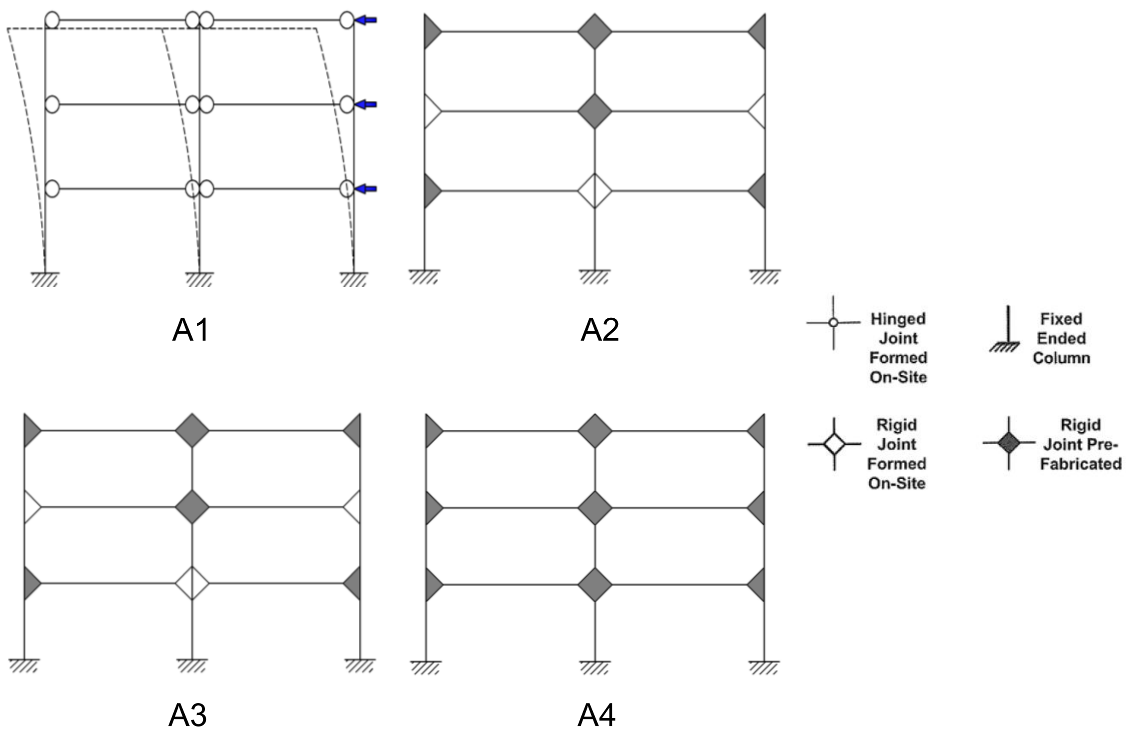
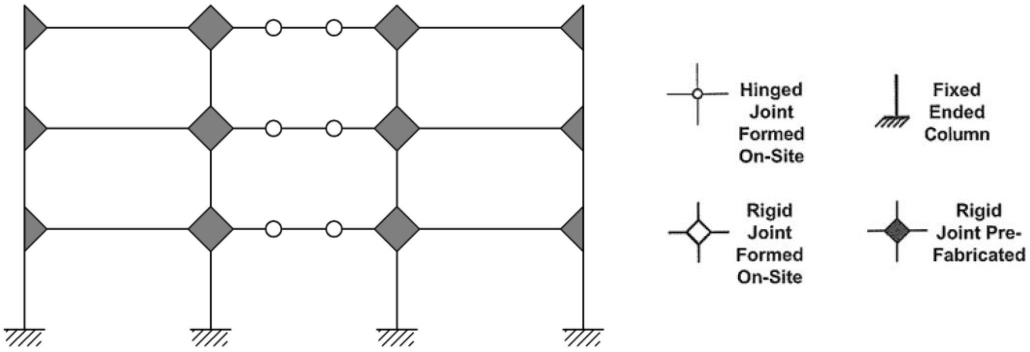


FIG. 2 TYPE A FRAMES

b) *Type-B Frames* – Type B frames shall consist of precast beam units passing through columns (*see* Fig. 3). These shall be achieved by adopting the following arrangement:

1) System B1 – Columns shall be 1 storey high and spliced at each floor level. Precast beams run through the columns and are spliced at point of contraflexure. It shall be ensured that beam splices are avoided at end spans. Slab units shall be simply supported.



B1

FIG. 3 TYPE B FRAME

c) *Type-C Frames* – Type C frames shall consist of monolithically fabricated beam column units such as cruciform, T/L-units, H-frames, portal frames, etc. These shall be achieved by adopting either one or a combination of the following arrangements:

1) *System C1* – Single storey portal frames shall be placed alternately and simply supported at floor levels. Orthogonal beams and beams connecting the portal shall be simply supported or continuous based on the design requirements. Slab units shall be simply supported.

2) *System C2* – L-shaped and T-shaped frame units shall be placed simply supported on the base and on top of each other. Hinged or moment resisting connections shall be made between frame units at the mid-span of beams. Slab units shall be simply supported.

3) *System C3* – H-shaped frames with a cantilever beam shall be provided with rigid connection at the junction of beam and column. Hinge or moment resisting connections shall be provided at the mid-height of columns and centre of beams. Slab units shall be simply supported.

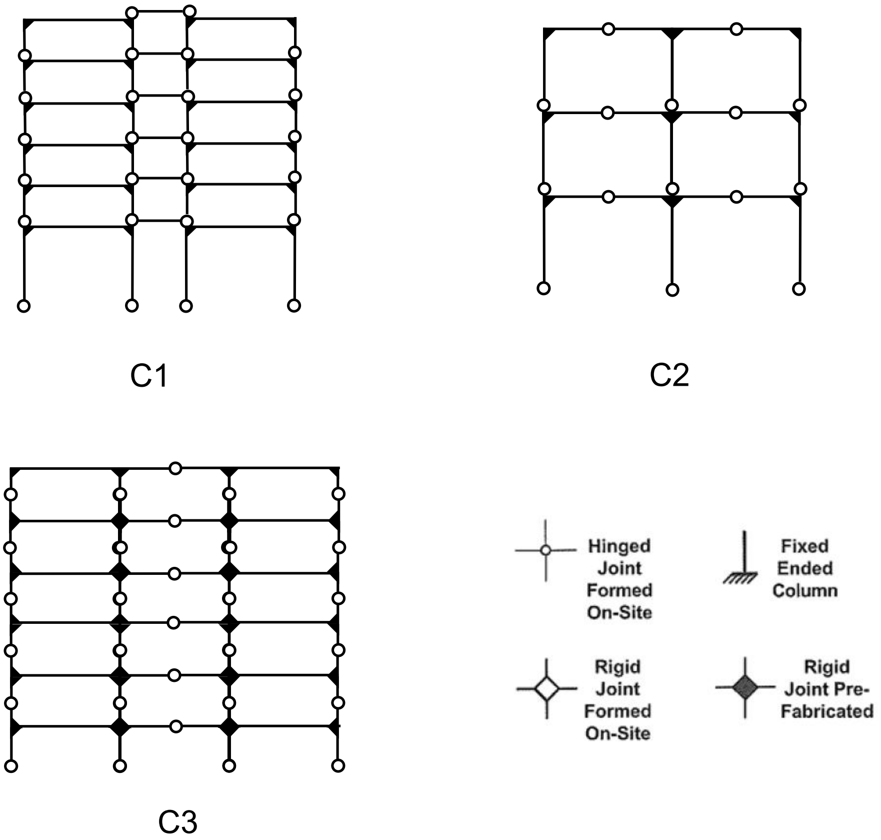


FIG. 4 TYPE C SYSTEMS

4.3.5.2 *Braced skeletal frames*

In this system, stability shall be provided by shear walls, shear cores or other bracing systems. Based on the ductility desired, the base of the columns and beam-column connections shall be pinned or rigid.

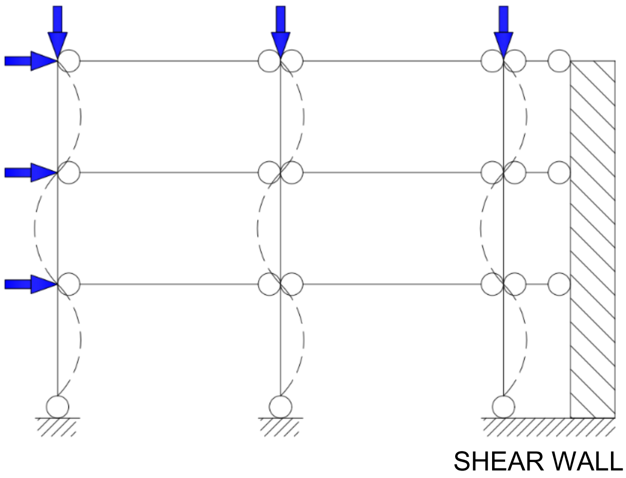


FIG. 5 BRACED FRAMES

4.3.6 *Wall Systems*

The distinction between the types of wall frames shall be based on the design of connections between individual concrete panels, which when jointed together form the structural wall. Wall systems shall be any of the following types (*see* Fig. 6).

a) Non-jointed wall systems
b) Emulative (monolithic) wall system
c) Jointed wall systems

4.3.6.1 In the non-jointed wall systems horizontal connections shall be designed as ductile connection. The vertical connections shall not be considered in the gravity and lateral load transfer. The wall panels shall be considered to act individually.

4.3.6.2 In the monolithic wall systems horizontal joints shall be designed as ductile connection. The vertical connections shall be designed as strong connections, so that their elastic limit is not exceeded in satisfying building's ductility demands.

4.3.6.3 In the jointed wall systems, the horizontal and vertical connections shall be designed as 'ductile', with energy dissipation occurring in the connection thereby contributing to building's overall ductility.

4.3.6.4 Combination of monolithic and jointed systems shall be adopted based on the performance requirements of the building.

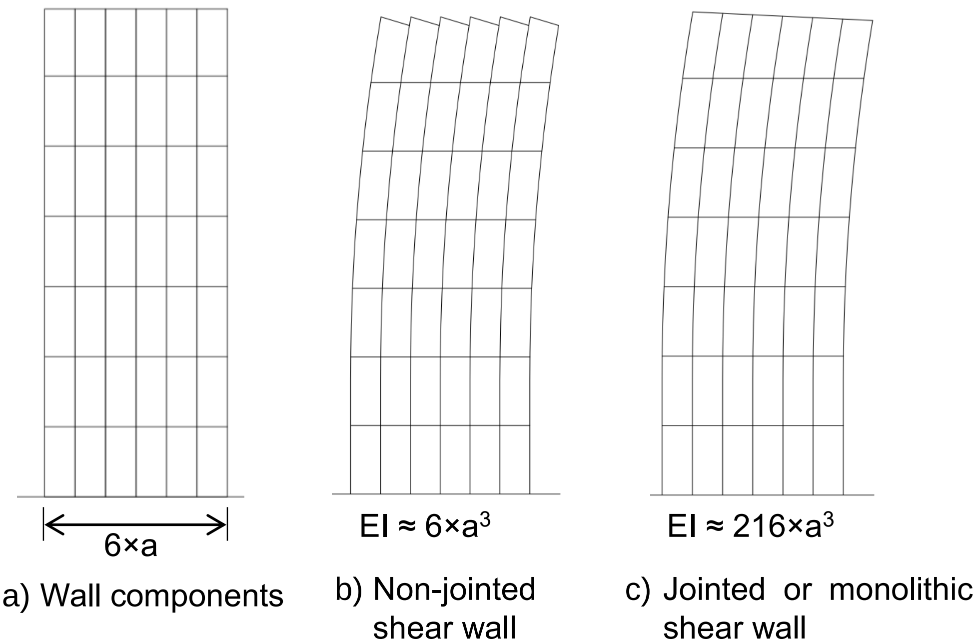


FIG. 6 SHEAR WALL BEHAVIOUR DUE TO CONNECTIONS

4.3.7 *Floor/Roof Systems*

Precast floor/roof systems shall act as a floor diaphragm, capable of effectively transferring horizontal forces to lateral load resisting system.

4.3.7.1 Minimum structural topping of 70 mm with reinforcing mesh or welded wire mesh shall be used in seismic zones III, IV and V, which can be reduced to 50 mm in seismic zone II. The minimum structural topping thickness shall be measured above the slab top level even at the highest camber location. The structural topping shall be provided on the entire floor.

4.3.7.2 Precast floor/roof systems spanning in a direction can be of types given in **4.3.7.3** to **4.3.7.6**.

4.3.7.3 *Hollow-core slab system*

This system is made up of prestressed precast concrete slabs with hollow cores (*see* Fig. 7). These systems can be efficient for multi-story buildings with moderate spans. Structural topping shall be provided to ensure diaphragm action. The HCS slab shall not be considered in diaphragm action.

a) The thickness of hollow core slabs varies depending on the span and load requirements, but typically range from 150 mm to 500 mm.
b) Standard width of hollow core slab may be 1200 mm or 2400 mm
c) Standard dimensions of hollow core slabs shall conform to good practice [6-7(18)]

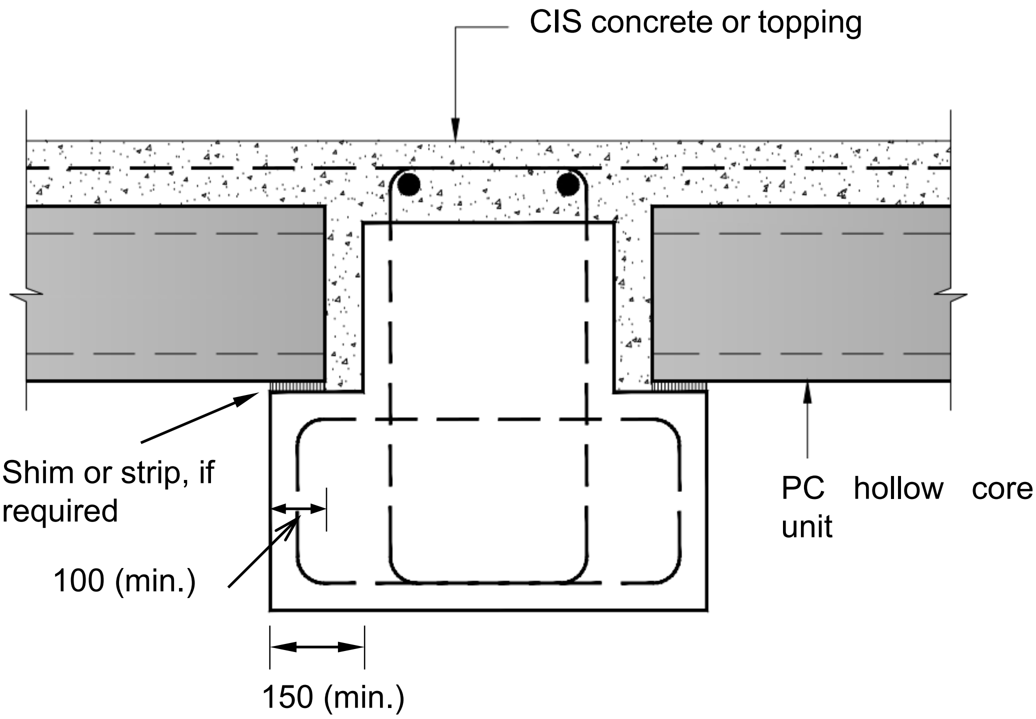


FIG. 7 HOLLOW CORE SLAB

4.3.7.4 *Double tee slab system*

This system is made up of precast concrete slabs with a double tee cross-section. The double tee shape provides greater strength and stiffness than a flat slab, making it suitable for larger spans and higher loads. These shall conform to accepted standard [6-7(18)]. Structural topping shall be provided to ensure diaphragm action. The double tee units shall not be considered in diaphragm action if the units are not connected for required force transfer.

4.3.7.5 *Solid slab system*

This system is made up of solid precast concrete slabs that are typically thinner than the equivalent hollow-core slabs. It shall be used for residential or commercial buildings with single unit slabs having shorter span. Depending on the connection between the slab and supporting elements, the complete slab with structural topping may be considered to act as diaphragm. This can also be designed to act as diaphragm without the structural topping concrete with proper connections.

4.3.7.6 *One-way / Two-way composite slab system*

Composite slab (*see* Fig. 8), also termed as half slab is a precast slab system cast in two stages. The first stage is to manufacture thin precast concrete panels, typically of about 60 mm to 85 mm thick, with the slab's bottom reinforcement and projected shear reinforcement in the form of truss. The projected reinforcement facilitates for multiple point lifting/handling as well as acts as shear connectors for in-situ deck concreting.

4.3.7.6.1 The slab panels shall be designed for overall thickness (precast and in-situ deck) as one-way or two-way in accordance with provisions of accepted standard [6-7(19)] and this code.

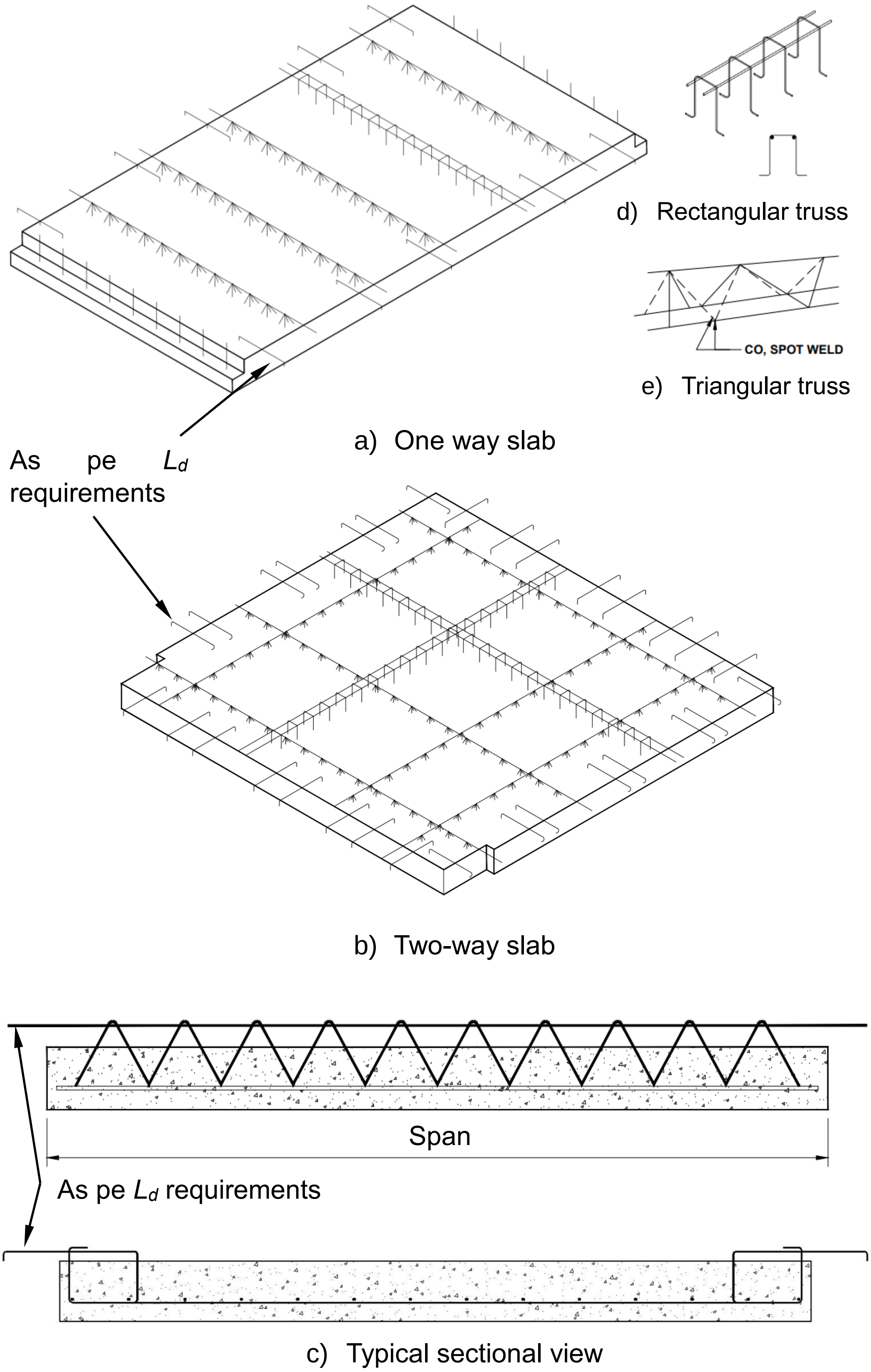


FIG. 8 PRECAST COMPOSITE SLAB PANELS

4.3.8 *Facade Systems*

Precast facade system shall be made up of following type of non-load bearing cladding panels. Good practice [6-7(20)] and **4.3.2** shall be considered for designing the connection of the facade elements.

a) Precast Insulated concrete panels:
b) Precast solid cladding panels:
c) Architectural precast decorative facade panels
d) Precast concrete fins

4.4 Hybrid System

The following systems are considered in precast hybrid system:

a) PRESSS system (utilisation of bonded or non-bonded prestressing tendons)
b) Mixed system (utilisation of CIS along with PC members or steel members)

4.4.1 *Precast Concrete Seismic Structural System (PRESSS) (Hybrid System)*

Precast concrete seismic structural system (PRESSS) is an equivalent monolithic system consisting of precast grouted connections incorporating bonded post-tensioned tendons. The main advantages of post-tensioning are deflection recovery and immediate occupancy of the structure. Two different system of PRESSS are explained in the following section**.** Application of these system shall be carried out by taking approvals from competent authorities and academic institutions.

4.4.1.1 *System-1 – Precast beam elements post-tensioned between columns*

This system shall include multi-storey high columns and precast beams which shall be slightly shorter than the clear span between columns, as shown in Fig. 9.

4.4.1.1.1 The beams shall be temporarily seated on steel brackets or props. Grout shall then be placed in the gap between beam ends and column faces, followed by post-tensioning operation and grouting of tendons.

4.4.1.1.2 The temporary supports shall be removed once the grout has achieved the required design strength.

4.4.1.1.3 Tests have demonstrated that the behaviour of this system is comparable to equivalent monolithic prestressed concrete construction and that the system can be utilised for the design of fully ductile moment resisting frames.

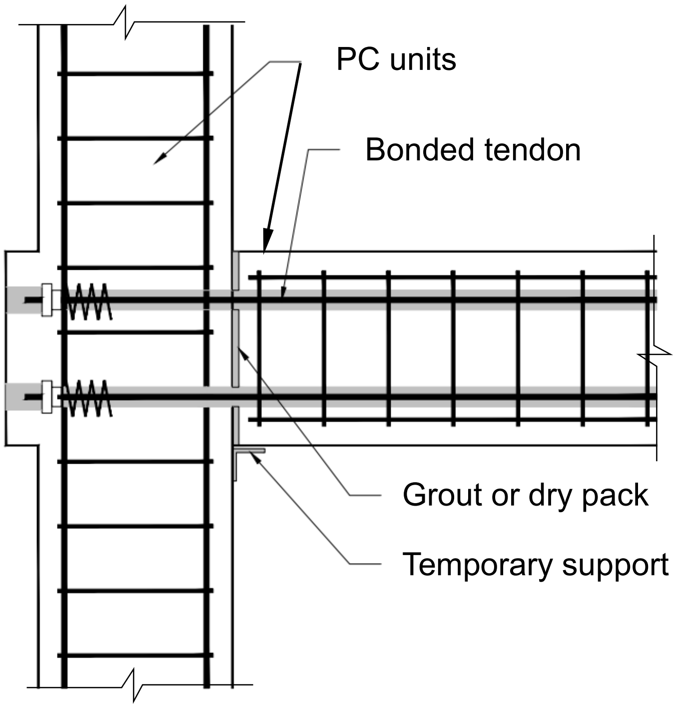


FIG. 9 SYSTEM-1: PRECAST BEAM ELEMENTS POST-TENSIONED BETWEEN COLUMNS

4.4.1.2 *System-2* – Supported precast beam elements post-tensioned between columns.

In this system the beams shall be seated on corbels that transfer gravity loads to the adjacent columns. The beams shall be either built prismatic or with dapped ends, depending on the position of the corbel (see Fig. 10) and then post-tensioned.

4.4.1.2.1 The columns in this system shall normally be one-storey in height.

4.4.1.2.2 Columns shall be connected through a mechanical coupler or a grouted steel sleeve.

4.4.1.2.3 This system shall be adopted for buildings designed to demonstrate elastic response.

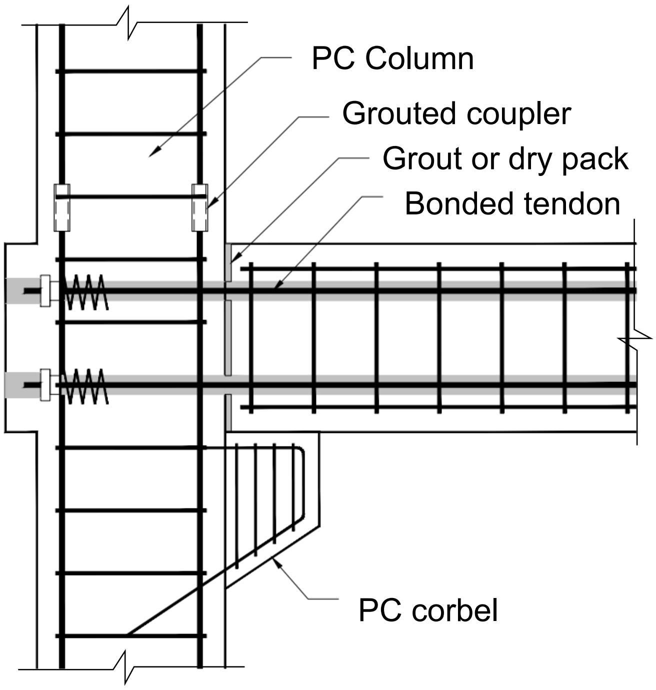


FIG. 10 SYSTEM-2: SUPPORTED PRECAST BEAM ELEMENTS POST-TENSIONED BETWEEN COLUMNS

4.4.2 *Mixed System (Cast-In-Situ-Precast or Structural Steel-Precast)*

This system shall use pretensioned PC or RC beam shell units or PC beams as permanent formwork for CIS beams or structural steel beams (as shown in Fig. 11).

4.4.2.1 The precast shells shall typically be left permanently in position after the cast-in-place reinforced concrete core has been cast.

4.4.2.2 The precast U-beams or structural steel beams shall be designed to carry self-weight, and construction loads and act compositely with the reinforced concrete core when subjected to other loading in the completed structure.

4.4.2.3 Precast U-beams may not be connected by reinforcement to the cast-in-place concrete of the beam or column. If the interfacial shear found not sufficient then shear connector (protruding stirrups or ties) shall be provided between the interfaces.

4.4.2.4 The design shall ensure that, the composite beams shall develop plastic hinges during major earthquakes.

4.4.2.5 During construction, it shall be ensured that the inside surface of the shell beams is clean when the cast-in-place concrete is placed, otherwise sufficient bond between the shell and core cannot develop.

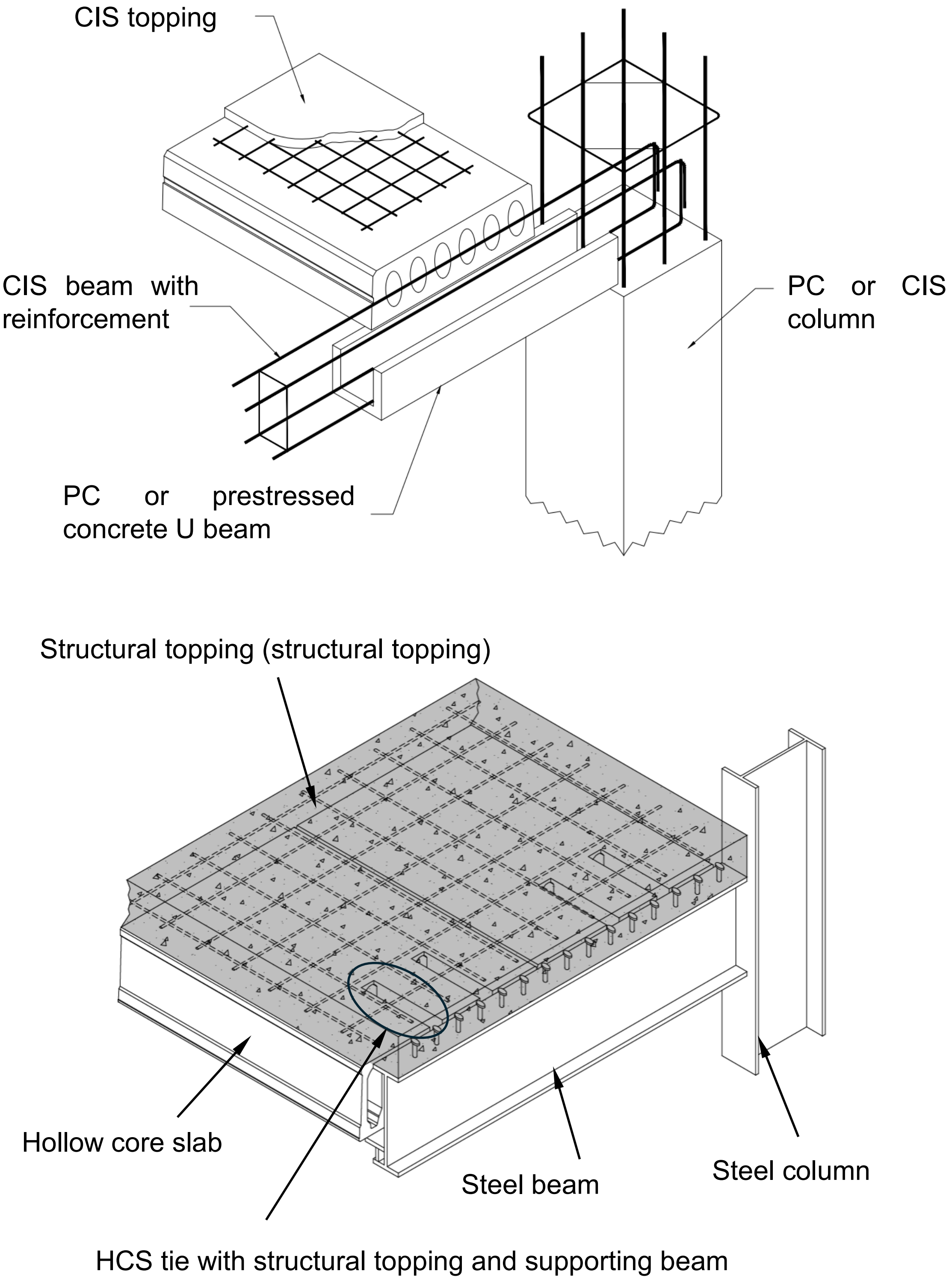


FIG. 11 MIXED SYSTEM

4.5 Advanced Precast Systems

4.5.1 *Cell Systems*

Precast concrete cell systems shall either in the form of closed cell elements or open cell elements. Complete structures can be made by combining cell elements. Annex B shall be referred for further details.

4.5.1.1 Cell elements for specific area of a structure, such as wet zones (for example, toilets and kitchens), shall be used and integrated with wall and floor systems with appropriate connections.

4.5.2 *3D Printed System*

Annex A shall be referred for further details.

4.5.3 *Design for Manufacturing and Assembly* (*DFMA) System*

Annex C shall be referred for further details.

5 STRUCTURAL ANALYSIS

5.1 General

The purpose of structural analysis is to estimate the forces and deformations of the structural members and system, to verify the compliance with the strength, serviceability, and stability requirements. Also, to ensure robustness and integrity of the members with the system. These effects include the distribution of forces and moments as well as the calculation of stresses, strains, curvatures, rotations and displacements in static or dynamic modes. For sustainable design aspects refer to **F-6**.

5.1.1 All the members and structural system shall be analysed to determine the maximum load effects as per methods given in good practice [6-7(3)] and clauses of this code.

5.1.2 To carry out analysis, the geometry, boundary conditions and behaviour of the structure need to be idealized both for global and local behaviour. The structure is idealised by considering it as made up of elements/components which can be linear, two dimensional or three dimensional.

5.1.3 Classical methods of mechanics or modern techniques such as finite element may be used for analysis depending upon the suitability of the mathematical model to evaluate the action effects with sufficient accuracy.

5.1.4 Precast with current state of the art technology could be analysed either as an emulative system or as a jointed system. However, emulative analysis is typically preferred where the structure is detailed such that the overall behaviour of the building in its design life will be similar to cast-*in-situ* (CIS) reinforced concrete building. In emulative approach, the precast structure shall be analysed as a monolithic and the joints in these designed to take the forces of an equivalent discrete system. Resistance to horizontal loading shall be provided by having appropriate moment and shear resisting joints or placing structural walls in orthogonal directions or otherwise.

5.1.5 No account shall be taken of rotational stiffness, if any, of the floor-wall or floor-beam joint in case of precast bearing wall buildings. The individual components shall be designed, taking into consideration the appropriate end conditions, loads given in **5.2** and at various stages of construction. In addition, members shall be designed for handling, erection and impact loads that might be expected during handling and erection as per **5.13**.

NOTES

1 Jointed construction using welded and bolted connections is not covered in this code. This system may be adopted with approval from competent authority and appropriate testing.

2 Rotational stiffness may be accounted for long/short term deflection and serviceability calculations as per **4.3.4**, provided that the approach is mutually agreed by the design team and approved by the Authority.

3 For horizontal members transferring gravity load and not part of the LLRS, the member may be designed based on pinned end conditions.

4 Linear/non-linear modal, P-delta analyses and other principles on analyses to be defined along with guideline for adoption of method.

5.2 Loads and Forces

The design shall include all the loading requirements as specified in good practice [6-7(21)]. Also, design consideration shall also be given to construction loads, any special requirements, for example for plant loads or storage loads and the load should be modified accordingly.

5.2.1 In structural design, account shall be taken of the dead loads, live or imposed loads, wind loads, forces such as those caused by earthquake effects, prestressing effects, crane loads, vibration, impact, natural disasters (flood, landslide, etc), blast and effects due to shrinkage, creep, temperature, etc, where applicable.

5.2.1.1 *Dead load*

Dead loads shall be calculated based on unit weights which shall be established taking into consideration the materials specified for construction or good practice [6-7(22)].

5.2.1.2 *Imposed Load*

Imposed loads shall be considered as per good practice [6-7(23)]. A minimum construction load (as per design requirement) of 1.0 kN/m^2 or construction traffic load shall be adopted for design, if not specified in the contract document. However, due consideration shall be given to actual possible construction loads.

5.2.1.3 *Wind load*

Wind load shall be considered as per good practice [6-7(24)].

5.2.1.4 *Construction traffic load*

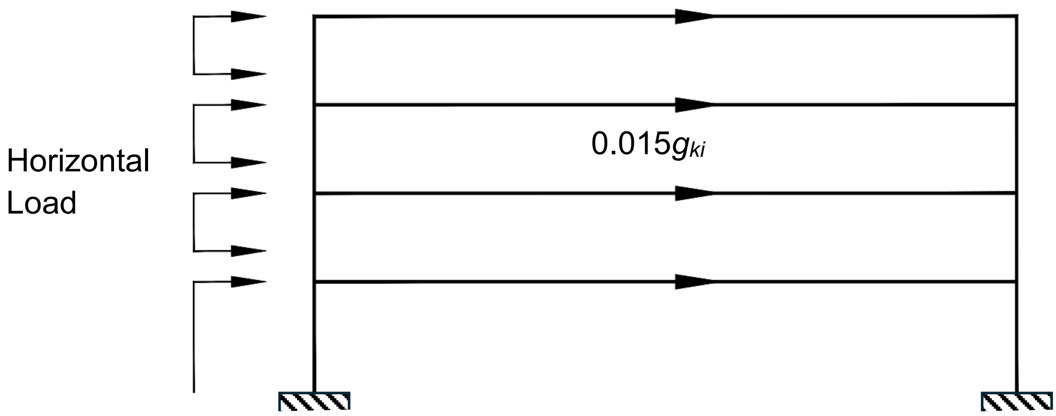
Construction traffic load shall be assumed in accordance with the project requirements. A minimum traffic load (as per design requirement) of 1.0 kN/m^2 or imposed load shall be adopted for design, if not specified in the contract document.

5.2.1.5 *Seismic load*

The seismic forces shall be calculated in accordance with the relevant part of good practice [6-7(25)].

5.2.1.6 *Notional horizontal load*

Notional horizontal load (as shown in Fig. 12) shall be taken as not less than 1.5 percent of the characteristic dead load and accidental loads such as earth movement, impact of construction vehicles.



g_{ki} characteristic dead load (including possible permanent loads)

i number of floors

FIG. 12 NOTIONAL HORIZONTAL LOAD AT FLOOR LEVELS

5.2.1.7 *Shrinkage, Creep, and Temperature effects*

The effects of shrinkage, creep and temperature shall be considered according to good practice [6-7(3)]. Special literature can be referred to for critical structures.

5.2.1.8 *Environmental loading*

The effects of thermal loading and changes in values of creep and shrinkage due to environmental exposure shall be considered according to good practice [6-7(3)], if not provided by the competent authority in the design basis report.

5.2.1.9 *Other forces and effects*

In addition, relevant Clauses of good practice [6-7(3)] shall be followed for additional forces such as snow load, liquid retaining loads, impact due to equipment, cranes etc.

5.2.2 *Load Combinations*

Basic load combination shall be as per good practice [6-7(3)]. In addition, precast specific load combinations specified by the competent authority or given in this code shall be adopted.

5.2.2.1 Factor of safety/ Partial safety factor for load combinations

Load and material safety factors shall be as per good practice [6-7(3)]. Precast specific partial safety factors given at various sections of this code shall be adopted accordingly.

5.3 Effective Span

5.3.1 Except for the purely simply supported spans, the effective spans for all elements shall be estimated as per the relevant clauses of good practice [6-7(3)].

5.3.2 Effective span for all elements during the temporary erection stage are to be considered based on the temporary support condition.

5.3.3 The effective span for simply supported elements shall be considered as the distance between the centre of the bearing pads or shims at each end. Where a group of shims is used only the shims or pads closes to the end of the elements shall be considered as governing case.

5.4 Stiffness

5.4.1 *Relative Stiffness*

The relative stiffness of the member shall be calculated based on the moment of inertia of the section considering gross section, transformed section and cracked section as per the guidelines provided in good practice [6-7(3)].

5.4.2 *Stiffness Modifiers*

The stiffness modifiers shall be considered as per the guidelines of good practice [6-7(25)].

5.4.3 *Critical Sections for Moment and Shear*

The critical sections for moment and shear shall be considered as per good practice [6-7(3)] along with the following clauses.

5.4.3.1 For L beams and inverted Tee beams where the imposed element loads are near the bottom of the beam, within 30 percent of the depth. In such instances the critical section shall be at the face of the support except for the beams where the beam and column junction are designed monolithic or with emulative connections.

5.4.3.2 Critical section for shear as per good practice [6-7(3)] is shown in Fig. 13.

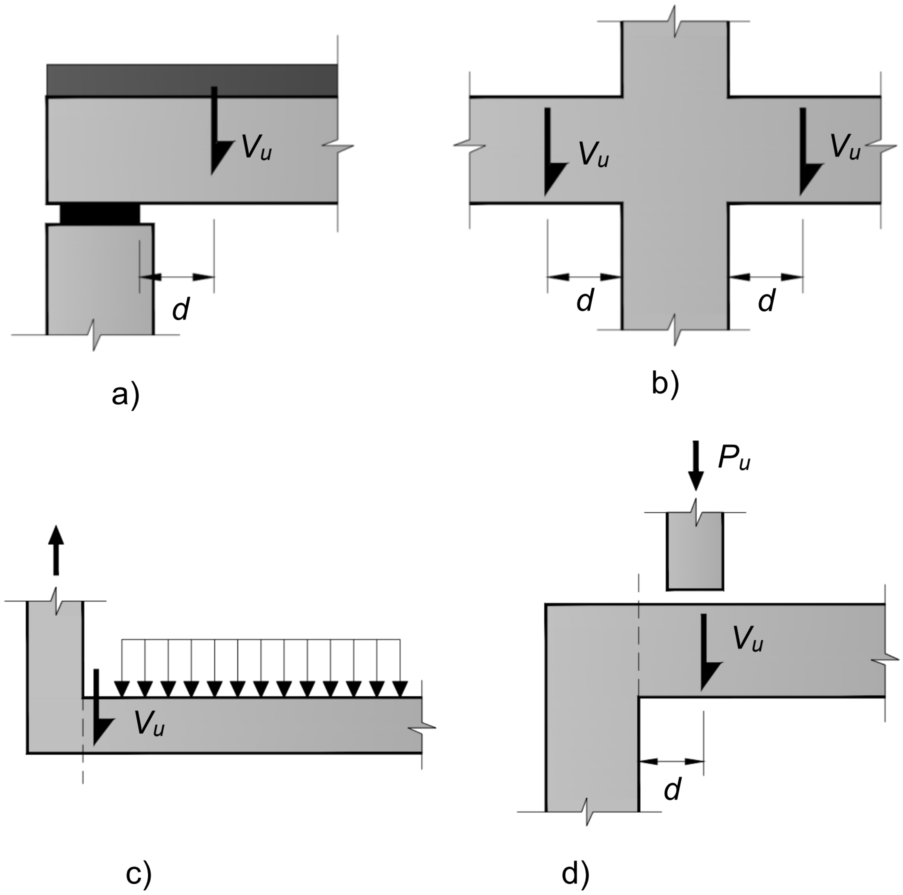


FIG. 13 CRITICAL SECTION FOR SHEAR

5.5 Concentrated Loads on Floor Slabs

5.5.1 Concentrated loads shall be applied as per good practice [6-7(23)]. Effective width for slabs carrying concentrated loads shall be calculated as per good practice [6-7(3)] along with the following clauses.

5.5.2 The load distribution for hollow core slab (HCS) depends on the one-way action of the plank and the cast in place structural topping. The effective width for hollow core slabs shall be calculated as per **5.5.3**.

5.5.3 Moments and shears created by line and concentrated loads be resisted by an effective section as described in Fig. 14. If the total deck width, perpendicular to the span, is less than the span, modification may be required. Also, the following limitations need to be considered:

a) As the width of the system becomes narrower than the span length, the effective resisting widths will become narrower.

b) For extremely high span-depth ratios (more than approximately 50), the effective section at mid-span shall be reduced by 10 to 20 percent.

c) For spans less than about 3 m, the effective width at the support may become narrower.

d) Local load concentrations can cause longitudinal splitting failures due to transverse bending in the system and punching shear failure. The magnitude of concentrated loads shall be limited to minimise such failures.

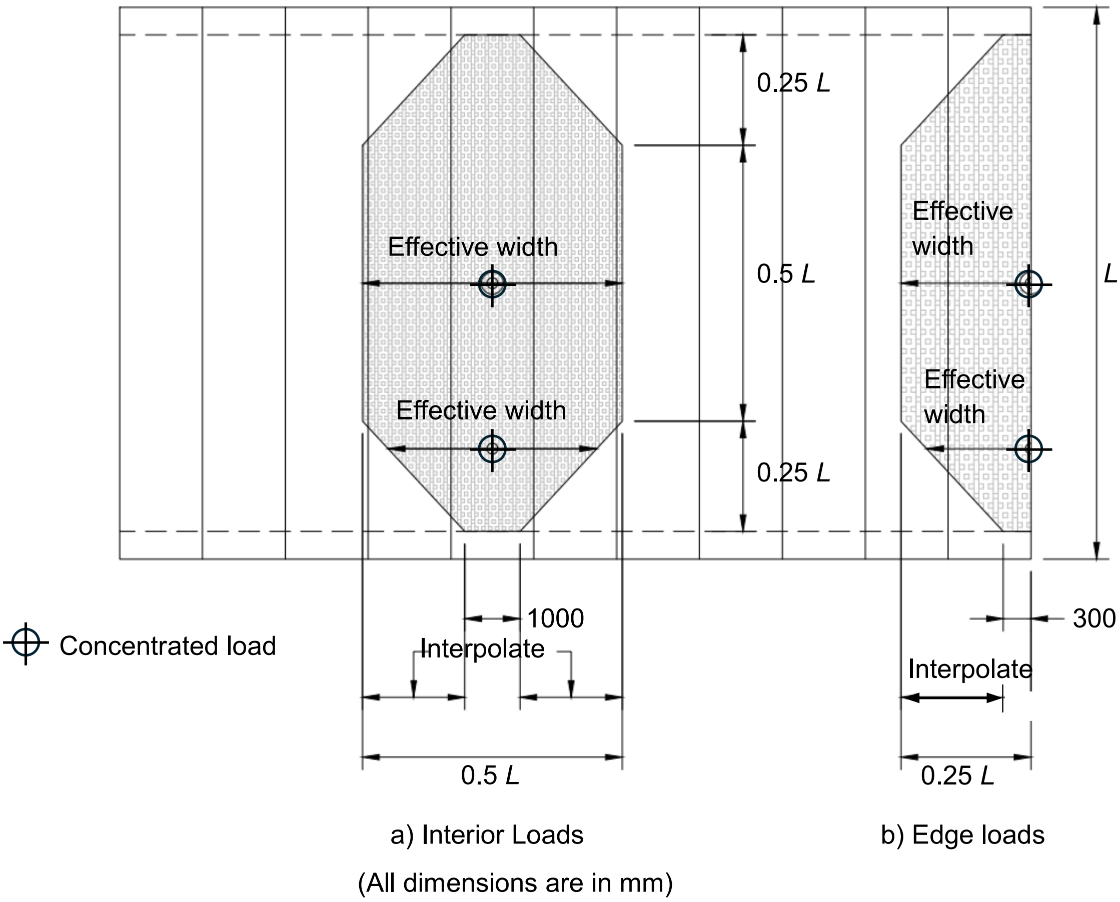


FIG. 14 MOMENT AND SHEAR DISTRIBUTION WIDTHS FOR HCS

5.6 Stability Design

5.6.1 *Design Philosophy*

a) The overall stability of the complete structure must be checked.

b) A structure comprising precast elements shall possess adequate stability to resist wind load and other lateral loads.

c) Cross walls or sway frames shall be so arranged, as far as practicable to provide lateral stability.

d) If lateral loads are marginal, stability shall be checked for a minimum notional horizontal force as shown in Fig. 12.

e) Consideration shall be given to lateral stability during all stages of construction and erection where the behaviour of the precast elements may differ from the permanent condition. Adequate propping and bracing shall be provided at all stages of construction to ensure stability is always maintained. The temporary works scheme shall provide sufficient details including propping layouts for all stages of construction including the sequencing and timing of the dismantling.

f) Inverted T and L beam shall be checked for one side loading condition during construction and service stages along with appropriate load combinations.

g) The strength of grout shall be at least 50 percent of the design strength before application of any other loads (temporary or permanent) on the element. However, cracking and stress checks shall be carried out.

h) Particular attention shall be given to stability and bracing requirements on high-risk structures such as long span beams and high-rise buildings.

j) Temporary anchors shall be designed for proper alignment and safety of the elements. Also, appropriate washers shall be used.

5.6.1.1 *Overturning*

Stability against overturning shall be checked according to good practice [6-7(3)] requirements. For L and inverted T beams, lateral support shall be provided during construction to avoid stability related failures.

5.6.1.2 *Sliding*

Stability against sliding shall be checked according to good practice [6-7(3)] requirements. All the precast members during construction shall be propped or anchored to prevent sliding from the supporting structure. Minimum bearing as per **5.10** shall be followed.

5.6.1.3 *Probable variation in dead load*

Variation of dead load during construction of in-situ part of a precast structure shall be considered. The design shall be checked and if necessary revised if major variation in in-situ concrete thickness/length/width is observed. Pouring of structural topping above the long span elements shall be monitored to have the required pouring depth measured from top of the highest point (camber point).

5.6.1.4 *Moment connection*

Moment connection shall be used for LLRS frames. Precast concrete structures with pin jointed frames or members shall be provided with structural walls to ensure transverse stability. Integrity ties between the elements shall be provided.

5.6.1.5 *Lateral sway*

Relevant clauses of good practice [6-7(26)] shall be followed to check the stability against lateral sway.

5.6.1.6 *Lateral load resistance system design*

The lateral load resistance system (LLRS) design shall be in accordance with good practice [6-7(27)] provisions with the guidelines stipulated in **4**. Additional impact of lateral loads such as earth fill, or liquid/snow retention shall be analysed as per the project requirements.

5.7 Durability Design

5.7.1 *Design Philosophy*

The following factors shall be considered for achieving the design life and durability of a precast structure:

a) Shape and size of the precast unit
b) Concrete constituents
c) Concrete cover
d) The environmental exposure
e) Protection against fire
f) Protection and maintenance
g) Production
h) Transportation, storage, and installation
j) Design of joint details

In addition to above requirements, the recommendations specified in good practice [6-7(3)], and relevant Indian standards shall be followed.

5.7.2 *Service Life*

5.7.2.1 The service life of any structure shall be specified in the design basic report by the client or considered based on good practice [6-7(3)].

5.7.2.2 For temporary structure the service life shall be considered as the period the structure is required to satisfy the intended function or as mentioned in the contract document.

5.7.2.3 The service life specified for a structure does not apply to architectural finishes, replaceable materials such as sealants, paints, non-structural grout, etc. The service life of such items shall be considered as per the manufacturer's guidelines and mutually agreed upon by all the stakeholders.

5.7.3 *Shape of Precast Units*

5.7.3.1 The precast unit shall be designed and detailed to have sufficient drainage to avoid standing water or excessive moisture.

5.7.3.2 Sharp corners or sudden changes or narrow corners or bands and grooves in a section causes stress concentrations that may lead to cracking or spalling of concrete and therefore shall be avoided. For sections with practical constraints, stress concentrations shall be checked and strengthening or local detailing shall be provided, as necessary.

5.7.3.3 Extra reinforcements shall be provided around the cutouts or opening if any present in an element. Larger cutouts shall be considered in the analysis to characterize the stress concentration and its effects on the design as per good practice [6-7(3)].

5.7.3.4 Buckling and instability must be prevented during the lifting and erection of long, slender precast units. For thin sections, the positioning of lifting inserts should be such that it prevents buckling of the compression flange, especially during the handling and manoeuvring of the elements.

5.7.4 *Concrete Cover*

For all concrete elements, the concrete cover requirements are per good practice [6-7(3)], except as noted in Table 2 shall be followed.

NOTE – Reduced cover requirements are allowed because precast elements are manufactured in a controlled environment. However, a controlled environment does not necessarily mean that precast members must be produced in a factory. Elements manufactured at the job site under similar factory-like controls also qualify as being produced in a controlled environment. If the cover requirements as per Table 2 are adopted, the client and the engineer in charge shall verify that the factory (or job site factory) satisfies the conditions as per the standard guidelines.

Table 2 Nominal Cover in Precast Elements
(*Clause* 5.7.4)

Sl No.	Exposure	Elements	Nominal Concrete Cover mm, *Min*
(1)	(2)	(3)	(4)
i)	Mild	All	20
ii)	Moderate	Slabs and Walls with bar dia. less than or equal to 32 mm	20
		Tendons and Strands 35mm dia. or smaller	25
		Walls and slabs with bar dia. greater than 32 mm and tendons greater than 35 mm dia.	30
		Beams, Columns, Pedestals. Stirrups, Ties and Tension Ties Not in Contact with Ground	Greater of d_b and 15 mm and not exceeding 35 mm
iii)	Severe	All	40
iv)	Very Severe	All	45
v)	Extreme	All	70

NOTES

1 The prescribed covers for precast elements are lesser than the covers noted in good practice [6-7(3)] to account for the greater control for proportioning, placing and curing inherent to precast concrete produced in a controlled environment.

2 Controlled environment does not imply that the precast members shall be manufactured in a factory. Elements manufactured at the jobsite or in a temporary factory also qualify under these requirements, if the controls are equal to that normally adopted in a factory. The client and engineer in charge shall verify the temporary factory and certify the same, if the cover requirements in Table 2 are adopted.

3 d_b is bar diameter

5.7.4.1 In respect of concrete cover requirements for protection against fire and corrosion, the provision of good practice [6-7(3)] shall be followed. The fire resistance of joints fillers, etc. shall comply with the fire resistance requirements of the precast members or as specified in **5.8**.

5.7.4.2 The cover to all brackets, fixings, etc shall comply with the minimum cover requirements specified for reinforcement as per the above table or good practice [6-7(3)].

5.7.5 *Protection and Maintenance of Joints and Connections*

5.7.5.1 The connection between the precast element shall be properly filled with cementitious high strength non-shrink non-metallic grout (preferably more than 50 MPa) to prevent corrosion, cracking and spalling of concrete.

5.7.5.2 Steel plates or inserts used in the connection shall preferably be protected with adequate cover or protective coating, except those used for temporary uses.

5.7.5.3 If sufficient cover is not available corrosion resistance material shall be used (based on project requirements and location) to achieve the connection or fixers.

5.7.6 *Other Effects*

5.7.6.1 To avoid concrete spalling and cracking, allowance shall be made for cumulative movement to decide the spacing between the joints. Width of joint shall include the production tolerances and effects of creep, shrinkage, settlement, thermal movements.

5.7.6.2 Apart from compliance with general requirements for durability, cracking and deformation, strength and stability, the following shall be considered:

a) Limiting the cracking and deformation arising from early thermal movement, creep, shrinkage, etc.
b) Minimising restraints on structural components by providing bearings or movement joints. If restraints are inevitable, the design shall take into consideration any significant effects (shrinkage and stresses due to deformation) that may arise, and reinforcement shall be provided as per good practice [6-7(3)].

5.8 Fire Resistance

5.8.1 *Fire Resistance Requirement*

5.8.1.1 The fire resistance of a structural element shall be expressed in terms of times in hours in accordance with good practice [6-7(28)]. General requirements for fire protection are given in good practice [6-7(29)].

5.8.1.2 The relevant clauses of good practice [6-7(3)] shall be applied to elements and joints having width more than 50 mm (other than specified below).

5.8.1.3 All joints in fire-prone structures shall be filled with mortar, grout, or concrete in accordance with the design requirements.

5.8.1.4 The joints between slab elements or hollow core elements with structural topping of more than 50 mm (minimum thickness of structural topping concrete) shall not be provided with any additional treatment for fire rating.

5.8.1.5 For slab elements without any structural topping, the joints shall be filled with grout till a depth at least one-third of the slab thickness or as required by good practice [6-7(3)].

5.8.1.6 The joints between the structural wall elements shall be filled with grout (50 MPa or higher) and for non-structural wall elements with cementitious mortar.

5.9 Structural Design of Precast Concrete Components

5.9.1 *Footings*

5.9.1.1 All the design and detailing requirements of good practice [6-7 (3) and (30)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.1.2 Precast footing with multiple elements stitched using appropriate connection arrangement shall be adopted, wherever required. However, footing subjected to vibration shall be without any joints preferably single unit or CIS.

5.9.1.3 The least thickness at the edge of a precast footing shall not be less than 250 mm. The thickness at the location of column or pedestal shall be as per good practice [6-7(3)].

5.9.1.4 The connections shall be detailed as per Section 6 of this code and shall ensure proper force transfer between the elements. (to be discussed).

5.9.1.5 Detailing of column, pedestal and wall connections to the footing elements shall be as per **6**.

5.9.2 *Walls*

5.9.2.1 All the design and detailing requirements of good practice [6-7 (3) and (30)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.2.2 Walls subjected to marginal shear forces, minimum longitudinal and transverse reinforcement shall be 0.1 percentage of gross area otherwise limits of good practice [6-7(3)] shall be adopted.

5.9.2.3 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.2.4 Walls shall be tied to the intersecting elements, such as floor, column, other walls and footing utilising appropriate tie or connection.

5.9.3 *Shear Wall*

5.9.3.1 All the design and detailing requirements of good practice [6-7 (3) and (30)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.3.2 Minimum reinforcement for structural wall shall be as per good practice [6-7(3)].

5.9.3.3 At least one continuous vertical tie of 12 mm diameter or higher shall be provided from foundation to terrace at each end of the structural wall using Type 2 coupler or any other connection with appropriate lapping or welding.

5.9.3.4 The connections shall be detailed as per **6** of this code and shall ensure proper force transfer between the elements.

5.9.3.5 Walls shall be tied to the intersecting elements, such as floor, column, other walls and footing utilising appropriate tie or connection.

5.9.4 *Floors/Slabs*

5.9.4.1 All the design and detailing requirements of good practice [6-7 (3), (2) and (31)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.4.2 Minimum reinforcement for slab elements with structural topping shall be 0.18 percentage of gross area. For slab elements without structural topping shall be as per [6-7(2) and (3)].

5.9.4.3 The thickness of structural topping concrete shall be considered if the maximum shear stress at any location is less than 0.4 MPa or shear reinforcement ensures the composite action with the floor slab elements.

5.9.4.4 The minimum grade of concrete for the structural topping shall be equal to M30 or as per design (whichever is higher).

5.9.4.5 The connections shall be detailed as per **6** of this code and shall ensure proper force transfer between the elements.

5.9.4.6 For PT members stress limits shall be as per good practice [6-7(2)].

5.9.4.7 For simply supported slab at least one third of the maximum positive reinforcement shall be extended till the centre of the bearing. For other cases, at least one fourth of the reinforcement shall extend into the support for a length of 150 mm.

5.9.5 *Columns*

5.9.5.1 All the design and detailing requirements of good practice [6-7 (3) and (30)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.5.2 Minimum reinforcement requirements shall be as per good practice [6-7(3)].

5.9.5.3 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.5.4 At least four continuous vertical ties of 12 mm diameter or higher shall be provided from foundation till the roof using Type 2 coupler or any other connection with appropriate lapping or welding.

5.9.5.5 Transverse reinforcement as per good practice [6-7(3)] and [6-7(1)] shall be provided in the members as well as the splice locations (grouted coupler, grouted duct, mechanical connections, etc.).

5.9.5.6 For connection using grouted coupler of height less than 250 mm, minimum cover of 12 mm shall be maintained to the transverse reinforcement. For all other cases cover shall be as per good practice [6-7(3)].

5.9.5.6 For connection using grouted duct/tube or any other minimum cover shall be as per good practice [6-7(3)].

5.9.6 *Beams*

5.9.6.1 All the design and detailing requirements of good practice [6-7 (2), (3) and (31)] shall be followed for members/elements along with any specific criteria given in this code.

5.9.6.2 Minimum reinforcement requirements shall be as per good practice [6-7(3)].

5.9.6.3 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.6.4 Transverse reinforcement as per good practice [6-7 (1), (2) and (3)] shall be provided in the members as well as the splice locations (grouted coupler, grouted duct, mechanical connections, etc.).

5.9.6.5 For connection using mechanical coupler of length less than 250 mm, minimum cover of 12 mm shall be maintained to the transverse reinforcement. In all other cases cover shall be as per good practice [6-7(3)].

5.9.6.6 For beam made composite to the CIS topping (T action or L action, in compression), the thickness of CIS shall be considered in the height of the beam, and the width of flange shall be calculated according to good practice [6-7(3)].

5.9.6.7 Stress limits for PT beams shall be as per good practice [6-7(13)].

5.9.6.8 For simply supported beam at least one third of the maximum positive reinforcement shall be extended till the centre of the bearing. For other cases, the reinforcement shall extend to the other member or to the support and shall develop f_y at the tension face of the support.

5.9.7 *Staircase/ Landing*

5.9.7.1 All the design and detailing requirements of good practice [6-7(3)] shall be followed for members along with any specific criteria given in this code.

5.9.7.2 Minimum reinforcement requirements shall be as per good practice [6-7(3)] and shall ensure proper force transfer between the elements.

5.9.7.3 The connections shall be detailed as per **6**.

5.9.8 *Composite Concrete Construction*

5.9.8.1 All the design and detailing requirements of good practice [6-7(3)] shall be followed for members along with any specific criteria given in this code.

5.9.8.2 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.9 *Insulated Panels/ Thermal Comfort*

5.9.9.1 All the design and detailing requirements of good practice [6-7(3)] shall be followed for members along with any specific criteria given in this code.

5.9.9.2 Minimum thickness of wythe (solid concrete) shall be 50 mm.

5.9.9.3 Individual wythe shall be connected to each using wythe connectors by providing solid zones or special reinforcements.

5.9.9.4 Maximum spacing between the reinforcements in the wythe shall be 250 mm or as per design.

5.9.9.5 For walls make of composite wythe, the solid zone shall be designed to transfer the shear demand on the wall and for moment transfer complete composite wythe section shall be considered.

5.9.9.6 Insulation material if provided shall have adequate bond with the concrete wythes to avoid splitting of junction, during handling.

5.9.9.7 The connections with other elements shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.10 *Composite Floors*

5.9.10.1 All the design and detailing requirements of good practice [6-7(3)] shall be followed for members along with any specific criteria given in this code.

5.9.10.2 No shear reinforcement shall be provided if the maximum shear stress at any location is less than or equal to 0.4 MPa.

5.9.10.3 The minimum grade of concrete for the structural topping shall be equal to M30 or as per design (whichever is higher).

5.9.10.4 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.11 *Others Structural Elements*

5.9.11.1 Any structural element shall be designed and detailed as per good practice [6-7(3)].

5.9.11.2 The connections shall be detailed as per **6** and shall ensure proper force transfer between the elements.

5.9.11.3 Any connection scheme found effective in force transfer shall be used, subjected to approval of competent authority.

5.10 *Design of Diaphragm*

For the stability of the precast concrete building horizontal loads due to wind and earthquake shall be transmitted to the LLRS through the floor acting as horizontal deep beam. However, in a precast slab system, the floor comprises individual units generally not connected to each other. A structural topping concrete is provided to act as the diaphragm, or the individual elements are connected. In this system, the diaphragm action shall ensure the following.

a) Collect and transfer lateral forces at each level to the lateral load resisting elements such as shear walls, moment frames, etc.
b) Tie individual lateral force resisting elements into a single lateral force resisting system.

5.10.1 Diaphragm action arises from the in-plane stiffness inherent to the floor system. As a result, substantial in-plane forces can develop in the diaphragm during lateral loading. In the context of precast concrete construction, the panelled nature of floor systems can pose challenges in the seismic design of diaphragms. These challenges may involve ensuring sufficient strength, stiffness, and, in some cases, ductility in both the diaphragm and its connections.

5.10.2 In case of buildings whose floors can provide rigid horizontal diaphragm action, the total shear in any horizontal plane shall be distributed to the various vertical elements of lateral forces resisting system, assuming the floors to be infinitely rigid in the horizontal plane.

5.10.3 In case of building whose floor, diaphragms cannot be treated as infinitely rigid in their own plane, the lateral shear at each floor shall be distributed to the vertical elements resisting the lateral forces, considering the in- plane flexibility of the diaphragms.

NOTE – Reinforced concrete monolithic slab-beam floors or those consisting of prefabricated/precast elements such as solid slabs, hollow core slabs or double tees with reinforced topping shall satisfy the requirements of **5.10.10**. In all cases, the precast elements need not be considered as part of the diaphragm except solid slabs with proper connectivity. The gravity load design, however, shall be composite including the structural topping as well as the precast element provided the interface shear at the topping and element face is analysed and designed for the same.

5.10.4 *Rigid diaphragms*

A diaphragm is classified as rigid if it can distribute the horizontal forces to the vertical components in proportion to their relative stiffness. Diaphragms of concrete slabs of concrete-filled metal deck with span-to-depth ratios of 3 or less in structures that have no horizontal irregularities are permitted to be idealized as rigid. The minimum thickness of structural topping concrete shall be as per **5.10.10**.

5.10.4.1 Where the diaphragm is very stiff compared to the vertical elements, as in a low aspect ratio, cast-in-place diaphragm supported by moment frames, it is acceptable to model the diaphragm as a completely rigid element.

5.10.5 *Flexible diaphragms*

A floor diaphragm shall be flexible, if it deforms such that the maximum lateral displacement measured from the chord of the deformed shape at any point of the diaphragm is more than 1.5 times the average displacement of the entire diaphragm or as per good practice [6-7(32)] guidelines. Flexible diaphragm can be adopted in modular structures having frequent opening such as substation, electrical rooms, industrial structures, etc.

5.10.5.1 Where the diaphragm is flexible compared with the vertical elements, as in some jointed precast systems supported by structural walls, it may be acceptable to model the diaphragm as a flexible beam spanning between rigid supports.

5.10.5.2 In other cases, it may be advisable to adopt a more detailed analytical model to account for the effects of diaphragm flexibility on the distribution of displacements and forces. Examples include buildings in which diaphragm and vertical element stiffness have approximately the same value, buildings with large force transfers, and parking structures in which ramps connect between floors and act essentially as bracing elements within the building.

5.10.6 *Topped diaphragms*

Topped floor and roof diaphragms include systems with In-situ concrete slab over precast RC planks and joists. The In-situ concrete slab is considered to act composite with the precast RC planks with sufficient surface roughness to transfer horizontal shear, so that the flexural strength of the precast component is enhanced by the added structural depth of the In-situ slab.

NOTE – In the computational model of the structure, the diaphragm shall be modelled considering the thickness of the topping/structural topping with extra dead load applied on top of the diaphragm to consider the precast planks or elements.

5.10.7 *In-plane diaphragm design loads and forces*

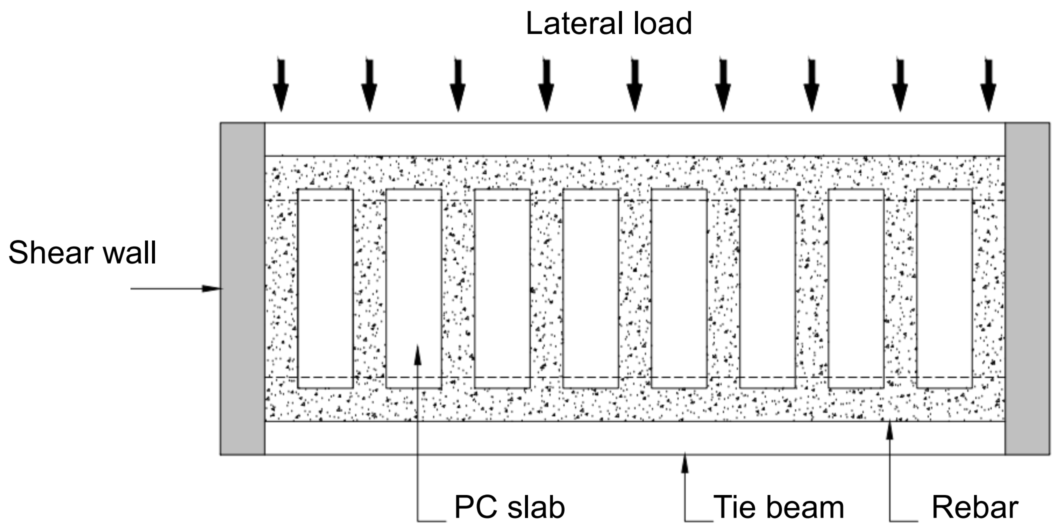
Topped floor and roof Diaphragms shall be designed to resist design In-plane inertial forces due to earthquake forces and wind loads from the structural analysis. Earthquake forces shall be calculated in accordance with good practice [6-7(35)] and Wind Loads shall be estimated in accordance with good practice [6-7(24)].

5.10.8 *Standard analysis methods for diaphragm design*

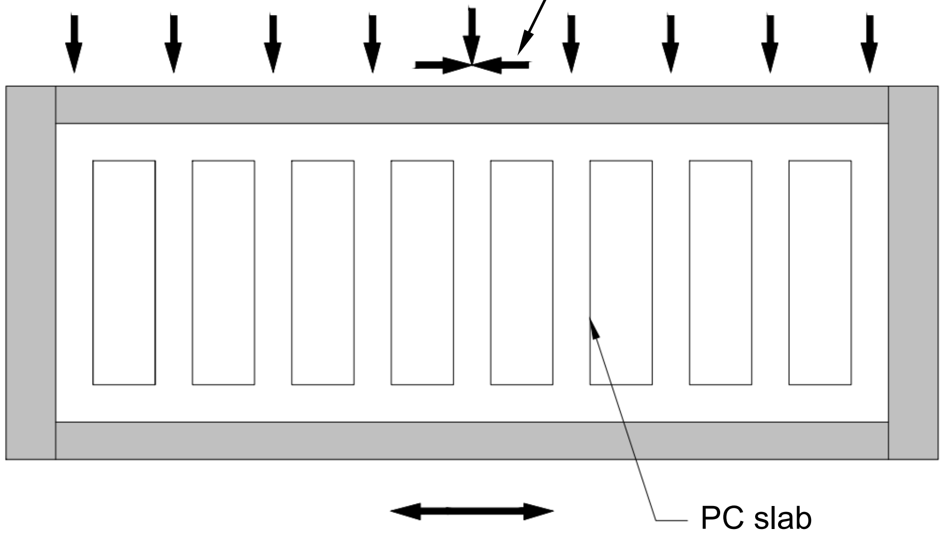
The magnitude of the inertia force at each floor level is estimated using a capacity design approach or a diaphragm design force distribution based on equivalent lateral loads. A key design step is to transform the diaphragm design forces into internal actions. For regular floor plans, a 'horizontal plate girder' analogy is typically used in design. In this approach, diaphragm design forces are typically applied at each level as a distributed in-plane load along the length of the diaphragm. The resulting girder internal forces are used to determine the amount of flexural reinforcement (chord steel), shear (web) reinforcement, and lateral system reaction load path reinforcement (collector steel). An irregular mass distribution in plan may require the design forces to take on a smeared load configuration as the mass distribution with respect to diaphragm depth has relevance in determining the proper web reinforcement. For more complex diaphragm configurations, a strut-and-tie method can be used. The strut-and-tie method accurately predicts the behaviour of floor diaphragms, in general, and may become the preferred method of diaphragm analysis (see Fig. 15 and Fig. 16).

5.10.8.1 Calculation of diaphragm in-plane design moments, shears, and axial forces shall be consistent with requirements of equilibrium and with design boundary conditions. It shall be permitted to calculate design moments, shears, and axial forces in accordance with one of (a) through (d):

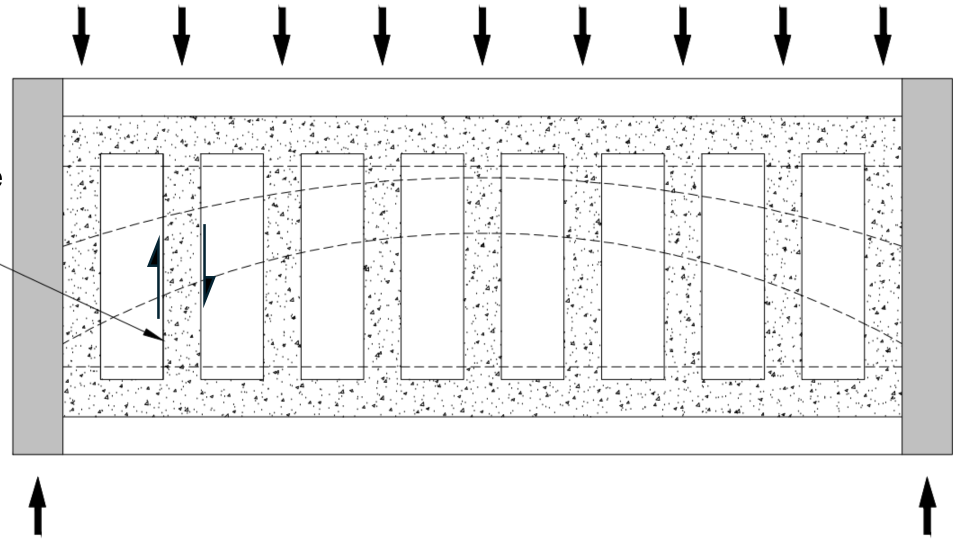
a) A rigid diaphragm model if the diaphragm can be idealized as rigid
b) A flexible diaphragm model if the diaphragm can be idealized as flexible
c) A bounding analysis in which the design values are the envelope of values obtained by assuming upper bound and lower bound in-plane stiffness for the diaphragm in two or more separate analyses
d) A finite element model considering diaphragm flexibility (semi rigid).



15A Diagonal truss



15B Vierendeel girder



15C Deep horizontal beam

FIG. 15 STRUCTURAL MODELS FOR FLOOR DIAPHRAGMS

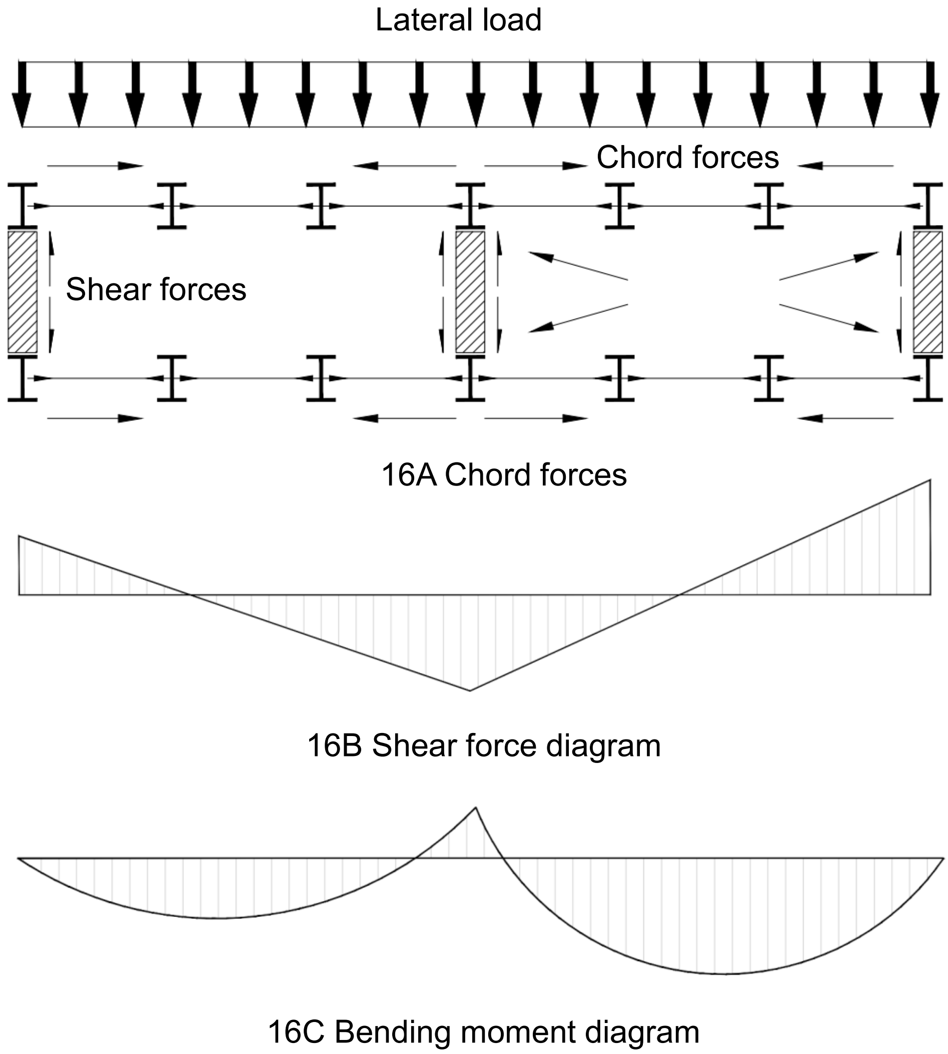


FIG. 16 DESIGN FORCES ON A DIAPHRAGM

5.10.9 *Materials*

5.10.9.1 Design properties of In-situ concrete for the topped diaphragms and diaphragm reinforcement shall be considered as per good practice [6-7(3)].

5.10.9.2 Minimum grade of structural topping concrete shall be 30 MPa or as per design (whichever is higher). Self-compacting concrete (SEC) shall preferably be used to have proper compaction between the conduits.

5.10.10 *Minimum thickness of topped diaphragms*

5.10.10.1 Topped floor and roof diaphragms shall have thickness as required for stability, strength and stiffness under factored load combinations.

5.10.10.2 Topped Floor and Roof Diaphragms that comprises RC planks composite with in-situ concrete slabs, the full thickness of the entire diaphragm must be sufficient to resist the design actions. In system with special precast slab elements such as hollow core slabs or double tees, the diaphragm thickness shall be limited to the in-situ structural topping concrete.

5.10.10.3 The minimum thickness of in-situ structural topping concrete over the precast RC planks/slabs for the topped diaphragms must be 50 mm (excluding the camber). Higher thickness of 70 mm is recommended in high seismic zones (Zone III, IV and V) to ensure adequate lapping and development of the higher diameter diaphragm reinforcement requirements.

5.10.11 *Diaphragm connections*

Connections between individual precast RC planks shall not be designed for any diaphragm forces in a topped diaphragm where the diaphragm thickness is limited to CIP structural topping only. Nominal connections required to facilitate the vertical alignment of the RC planks and flanges shall be sufficient.

5.10.12 *Opening and voids in the in-situ concrete topping slab*

The effects of openings and voids in the in-situ concrete topping slab shall be considered in the diaphragm design. Detailing around the openings and voids must be done in accordance with good practice [6-7(3)].

5.10.13 Collectors

5.10.13.1 Collectors shall extend from the vertical elements of the lateral-force-resisting system across all or part of the diaphragm depth as required to transfer shear from the diaphragm to the vertical element (as shown in Fig. 17). It shall be permitted to discontinue a collector along lengths of vertical elements of the lateral-force-resisting system where transfer of design collector forces is not required.

5.10.13.2 Collectors shall be designed as tension members, compression members, or both, in accordance with axial member of good practice [6-7(3)].

5.10.13.3 Where a collector is designed to transfer forces to a vertical element, collector reinforcement shall extend along the vertical element at least the greater of (a) and (b):

a) The length required to develop the reinforcement in tension
b) The length required to transmit the design forces to the vertical element through shear-friction in accordance with **5.12**, through mechanical connectors, or through other force transfer mechanisms.

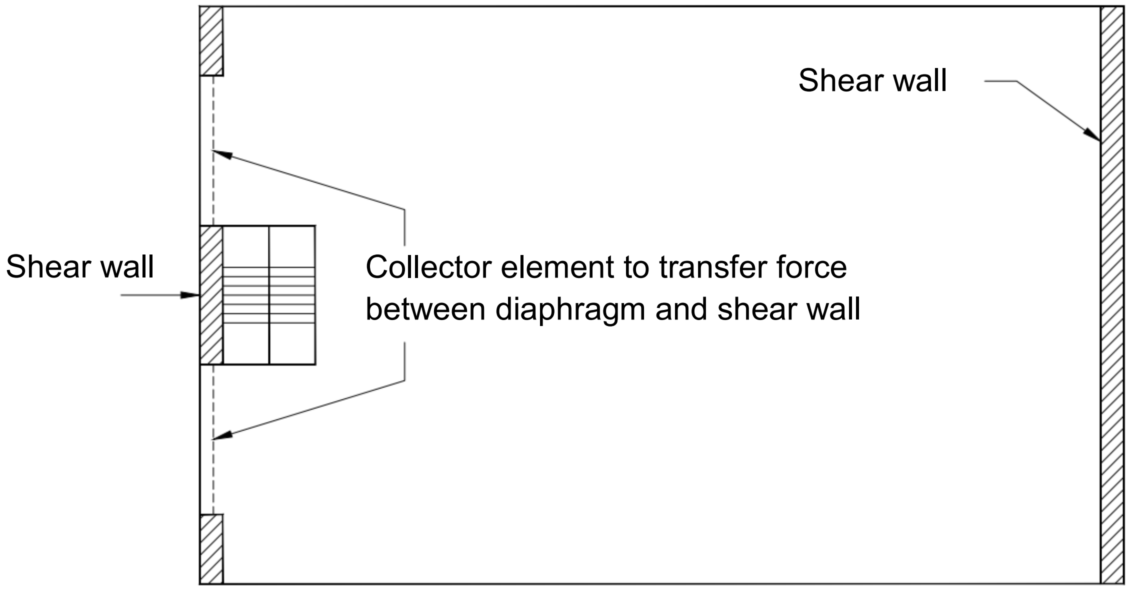


FIG. 17 COLLECTORS BETWEEN FRAMING ELEMENTS

5.10.14 *Reinforcement limits*

5.10.14.1 Reinforcement to resist shrinkage and temperature stresses shall be estimated according to relevant clauses of good practice [6-7(3)].

5.10.14.2 Reinforcement designed to resist diaphragm in-plane forces shall be in addition to reinforcement designed to resist other load effects, except reinforcement designed to resist shrinkage and temperature effects shall be permitted to also resist diaphragm in-plane forces.

5.10.15 *Reinforcement detailing*

5.10.15.1 Concrete cover for reinforcement shall be in accordance with good practice [6-7(3)].

5.10.15.2 Development lengths of deformed and prestressed reinforcement shall be in accordance with good practice [6-7(2) and (3)], unless longer lengths are required by high seismic zone requirements.

5.10.15.3 Splices of deformed reinforcement shall be in accordance with good practice [6-7(3)].

5.10.15.4 Bundled bars shall be in accordance with good practice [6-7(3)].

5.10.16 *Reinforcement spacing*

5.10.16.1 Minimum spacing of reinforcement shall be in accordance with good practice [6-7(3)].

5.10.16.2 Maximum spacing of deformed reinforcement shall be the lesser of five times the diaphragm thickness and 450 mm.

5.10.17 *Diaphragm and collector reinforcement*

5.10.17.1 Tensile or compressive force in reinforcement at each section of the diaphragm or collector shall be developed on each side of that section.

5.10.17.2 Reinforcement provided to resist tension shall extend beyond the point at which it is no longer required to resist tension at least for a length of L_d, except at diaphragm edges and at expansion joints.

5.10.17.3 Welded wire mesh of diameter 6 mm shall be used in the structural topping concrete to achieve the diaphragm reinforcement.

5.10.18 *Other parameters*

5.10.18.1 Heavy duty conduits having diameter less than or equal to 20 mm shall preferably be used.

5.10.18.2 Single junction box shall be used to conduct the conduits.

5.11 Designing of Bearing Region

5.11.1 *General*

The integrity of a bearing is preserved by three essential measures:

a) An overlap of reinforcement in reinforced bearings;

b) A restraint preventing loss of bearing due to movement; and

c) An allowance for the cumulative effects resulting from production and erection tolerances.

5.11.2 *Net Bearing Width of Non-Isolated Members*

The net bearing width for a member shall be as per Equation 1 with minimum value of 40 mm:

$$\textbf{Net bearing width} = \frac{\textbf{ultimate support reaction}}{\textbf{effective bearing length} \times \textbf{ultimate bearing stress}} \qquad \text{Equation 1}$$

The net bearing width should be increased to cater for any free movement permitted or rotation of the bearing about the support.

5.11.3 Effective Bearing Length

The effective bearing length of a member is the lesser of:

a) Actual bearing length;
b) One-half of bearing length plus 100 mm; or
c) 600 mm.

5.11.4 Design Ultimate Bearing Stress

The design ultimate bearing stress is based on the weaker of the two bearing surfaces and shall be calculated as follows:

a) $0.4f_{ck}$ for dry bearing on the concrete;
b) $0.6f_{ck}$ for bedded bearing on concrete; or
c) $0.8f_{ck}$ for contact face of a steel bearing plate cast into a member or support, with each dimension not exceeding 40 percent of the corresponding concrete dimension.

An intermediate value of bearing stress between dry and bedded bearings may be used for flexible bedding.

5.11.5 Net Bearing Width of Isolated Members

The net bearing width for isolated members should be that of non-isolated members plus 20 mm.

5.11.6 Minimum dimensions of bearing

The minimum requirement for bearing length shall be as per Fig. 18.

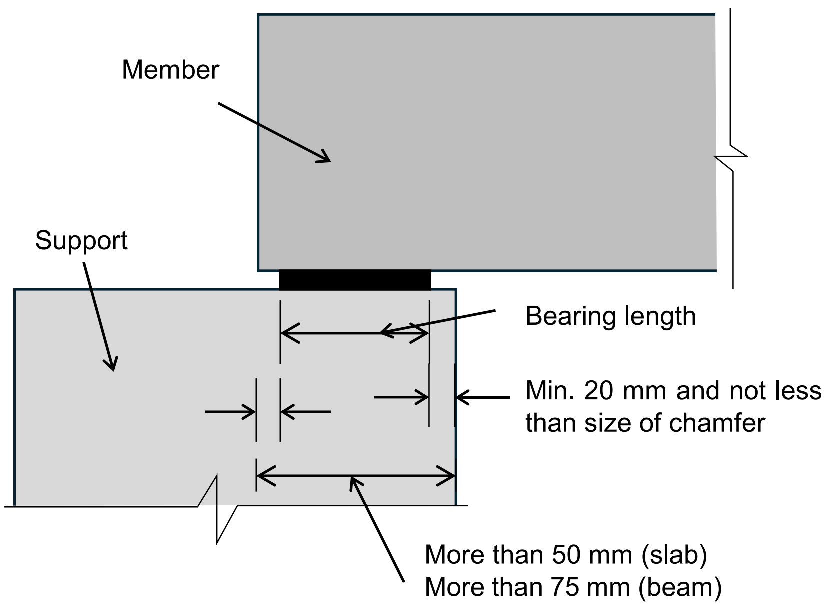
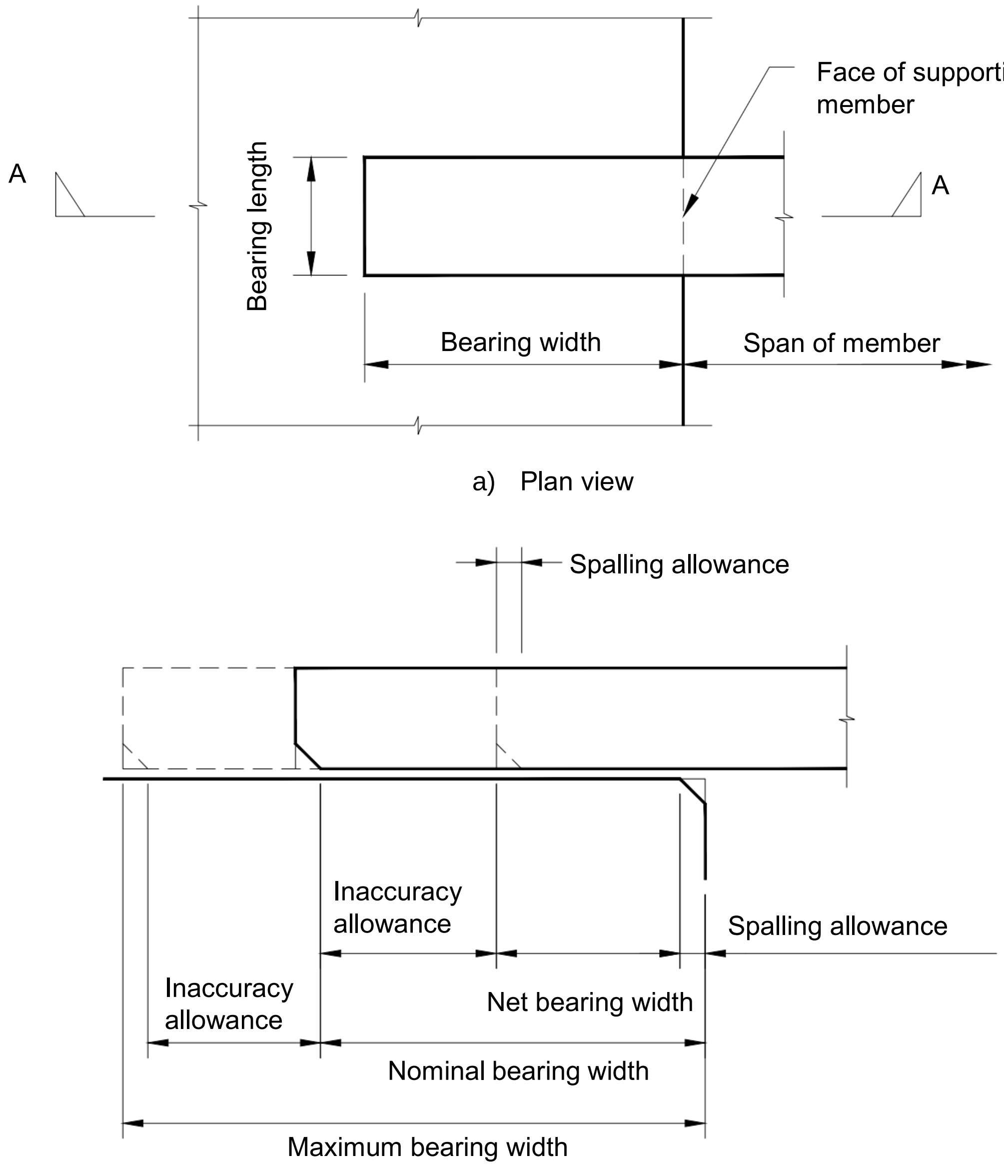


FIG. 18 BEARING LENGTH ON SUPPORT

5.11.7 *Detailing for Simple Bearing*

Over and above the net bearing width calculated above, allowances for spalling and constructional inaccuracies should be made in the nominal width selected (*see* Fig. 19). The effects of accidental displacement of a supported member during erection should also be considered. The minimum anchorage lengths of reinforcement required by the codal provisions should be provided.



a) Plan view

b) Section A-A

FIG. 19 SCHEMATIC ARRANGEMENT OF ALLOWANCES FOR BEARING

5.11.8 *Allowances for Spalling at Supports*

Recommendations for the allowances of ineffective portion of bearing area are given in Table 3 and Table 4. When determining the outer edge of a support or the end of a supported member, chamfers occurring within the areas subjected to spalling may be discounted.

Table 3 Allowances for Effects of Spalling at Supports
(*Clause* 5.11.8)

Sl No.	**Material of Support**	**Ineffective distance, measured from outer edge of support** mm
(1)	(2)	(3)
i)	Steel	0
ii)	Concrete ≥ M30	15
iii)	Concrete < M30	25
iv)	RC with outer edge less than 300 mm deep and vertical loop bar not greater than 12mm	Nominal cover to reinforcement on outer face of support
v)	RC with outer edge less than 300 mm deep and vertical loop bar is 16 mm or above	Nominal cover plus inner radius of bend of bars

Table 4 Allowances for Effects of Spalling at Supported Members
(*Clause* 5.11.8)

Sl No.	**Reinforcement at bearing of support member**	**Ineffective distance, measured from outer edge of support** mm
(1)	(2)	(3)
i)	Straight bar, horizontal loops or vertical loops of 12 mm diameter or less	Greater of nominal cover or 10 mm
ii)	Tendons or straight bars exposed at end of member	0
iii)	Vertical loops of 16 mm diameter or above	Nominal end cover plus inner radius of bend of bars

5.11.9 *Shims*

Plastic or metal shims shall be used depending on design requirements.

5.11.9.1 Steel shims should not be used at areas that are susceptible to spalling. The effect of load transfer via the shims should be designed for.

5.11.9.2 Maximum thickness of shims shall preferably be restricted to 40 mm.

5.11.9.3 Steel shims shall be used for joints having gap more than 40 mm. If metal shims more than 40 mm thickness are required to be used, proper tack welding shall be adopted.

5.11.10 *Allowance for Construction Inaccuracies*

The allowance for construction inaccuracies should cover deviations in setting out, site construction, manufacture and erection and it may be assessed from a statistical analysis of measured or predicted deviation. Alternatively, for supported members up to 15 m span and with average standards of accuracy, the allowance may be taken as the greater of:

a) 15 mm, or 3 mm per metre distance between the faces of steel or precast concrete supports;
b) 20 mm, or 4 mm per metre distance between the faces of masonry supports;
c) 25 mm, or 5 mm per metre distance between the faces of in-situ concrete supports.

5.11.11 *Bearings Transmitting Compressive Forces*

This type of joint is most commonly used for horizontal joints between load-bearing walls or columns. The joint shall be designed to resist all the forces and moments implicit in the assumptions made in analysing the structure as a whole and in designing the individual member to be joined. In the absence of more accurate information derived from a comprehensive programme of suitable tests, the area of concrete to be considered in calculating the strength of the joint in a wall or column shall be as per **6.3.2**. Particular attention should be paid to detailing the joint and joint reinforcement to prevent premature splitting or spalling of the concrete in the ends of the precast members.

5.11.12 *Other Forces at Bearings*

a) *Horizontal forces at bearing* – The horizontal forces at bearings may be induced by creep, shrinkage, temperature effects, misalignment, lack of plumb or other causes. When these forces are significant, the structural capacity of the supporting member may be impaired. A minimal force of 0.2 V_u (vertical or shear force on the bearing) shall be used in design. Allowances should be made by the provision of:

    1) Sliding bearings which allow longitudinal and lateral movement;
    2) Additional lateral reinforcement at the top of the supporting member; or
    3) Continuity reinforcement which ties the ends of the supported members together.

b) *Rotation at bearing* – Suitable bearings should be used to accommodate the rotations at end supports in particular for flexural members. Allowances should be made for any consequential increases in bending moments or bearing stresses due to rotations.

5.11.13 *Design of Bearing on Plain Concrete*

5.11.13.1 Plain concrete bearing (*see* Fig. 20) shall be used in situations where the bearing is uniform, and the bearing stresses are low.

5.11.13.2 In other situations, and in thin-stemmed components where the bearing area is less than 12500 mm^2, a minimum reinforcement equal to $N_u/0.65f_y$ (but not less than one bar of 10 mm diameter) is recommended. If horizontal load is not present, a minimum recommended value of $N_u = 0.2\ V_u$ shall be used.

5.11.13.3 The design bearing strength of plain concrete shall be calculated based on Equation 2 as given below:

Supporting area is wider in all sides than the loaded area (lesser of)	$V_{uR} = (0.45 f_{ck} A_1)\sqrt{\frac{A_2}{A_1}}$ $\sqrt{\frac{A_2}{A_1}}$ shall not exceed 2	a	Equation 2
	$V_{uR} = 2(0.45 f_{ck} A_1)$	b	
Other cases	$V_{uR} = 0.45 f_{ck} A_1$	c	

Where,
V_u Factored shear force
V_{uR} Design shear resistance
N_u Factored axial force (Minimum shall be 0.2 V_u)

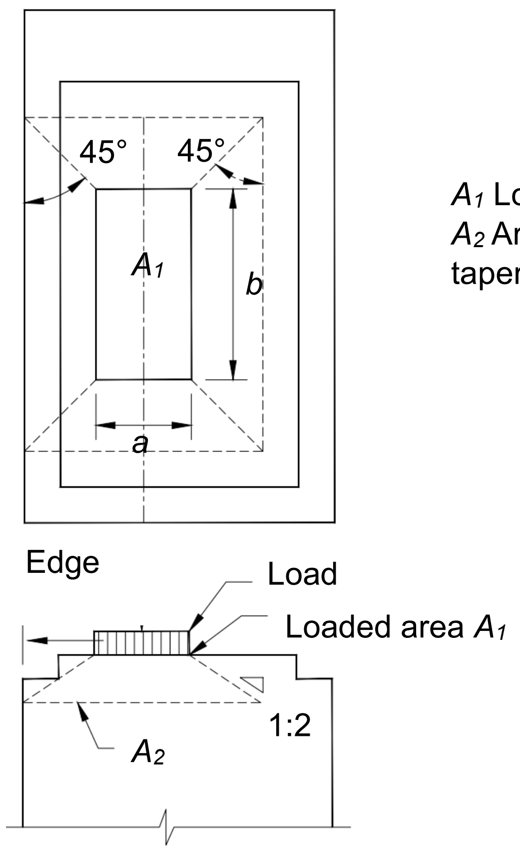
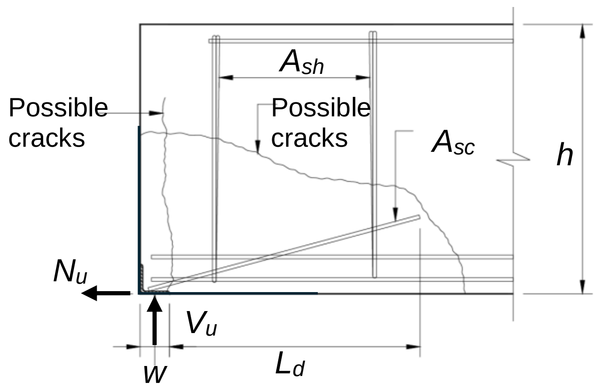


FIG. 20 BEARING ON PLAIN CONCRETE

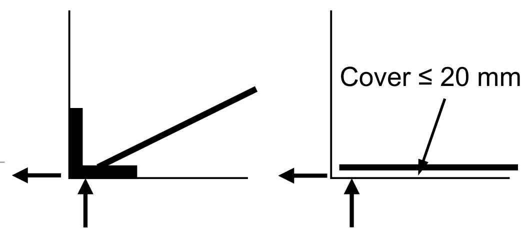
5.11.14 Reinforced Concrete Bearing (for thin stem elements and rectangular beams)

5.11.14.1 If the applied load V_u, exceeds the design bearing strength V_{uR}, as calculated by Equation 2, reinforcement shall be provided in the bearing area as per Fig. 21.

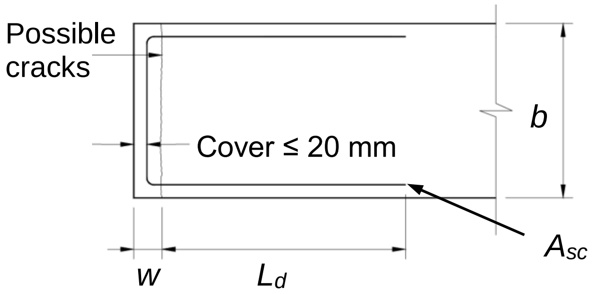
5.11.14.2 The area of reinforcement A_{vf} + A_n shall be calculated as per **5.12** and **5.11.16**. This reinforcement shall be appropriately developed on each side of the vertical crack by development length, hooks, or welding to an anchor bar, bearing plate, or angle.



a) Side view with bearing plate



- Detailing of bearing location with bearing plate or without bearing plate



b) Plan view without bearing plate

FIG. 21 REINFORCED CONCRETE BEARING

5.11.14.3 The area of vertical shear reinforcement shall be calculated as follows.

$$A_{sh} = \frac{(A_{vf} + A_n) f_y}{\mu f_{ys}} \qquad \text{Equation 3}$$

Where,

f_y yield strength of tension reinforcement,
f_{ys} yield strength of shear reinforcement,
A_{vf} area of shear friction reinforcement,
A_n area of tension reinforcement,
μ coefficient of friction as per Table 5

5.11.14.4 Stirrups or welded-wire reinforcement used for diagonal tension reinforcement may be considered to act as A_{sh} reinforcement and is not additive to shear reinforcement.

5.11.14.5 When components are subjected to bearing force more than $0.45 f_{ck} A_1$ confinement reinforcement in all directions shall be provided. A_1 shall be considered as per Fig. 20.

5.11.15 *Dapped End bearing (Thin Stem and Regular Beams)*

5.11.15.1 Dapped end members shall be designed for the potential failure modes shown in Fig. 22 to Fig. 24 with the reinforcement required for each consideration.

5.11.15.2 Dap reinforcement shall be provided in all cases where one or more of the following conditions:

a) The depth of the recess exceeds the lesser of 0.2H or 200 mm
b) The length of the recess (L_p in Fig. 22) exceeds 300 mm for non-thin-stemmed components and the nib (the concrete section above the dap) is not designed for the full flexural and shear capacity.
c) For non-thin-stemmed components, less than 1/3 of the main flexural reinforcement extends to the end of the component above the dap.

5.11.15.3 Thin-stemmed components such as double tees, T beam, etc. shall be designed with the following additional consideration:

a) Stem widths 125 mm or less
b) Vertical hanger reinforcement or inclined reinforcement at an angle greater than 90 degrees measured from horizontal
c) Dap height <= 0.5h

5.11.15.4 The design equations given in this section shall be considered for cases where shear span-to-depth ratio (a_v/d) shall not exceed 1.0.

5.11.15.5 The yield strength of reinforcement shall be restricted to 415 MPa.

5.11.15.6 For short, shallow recesses, the hanger reinforcement A_{sh}, and A'_{sh}, shall not be necessary. Confinement reinforcement A_v and flexural reinforcement $A_{vf} + A_n$, in accordance with **5.11.14** shall be provided.

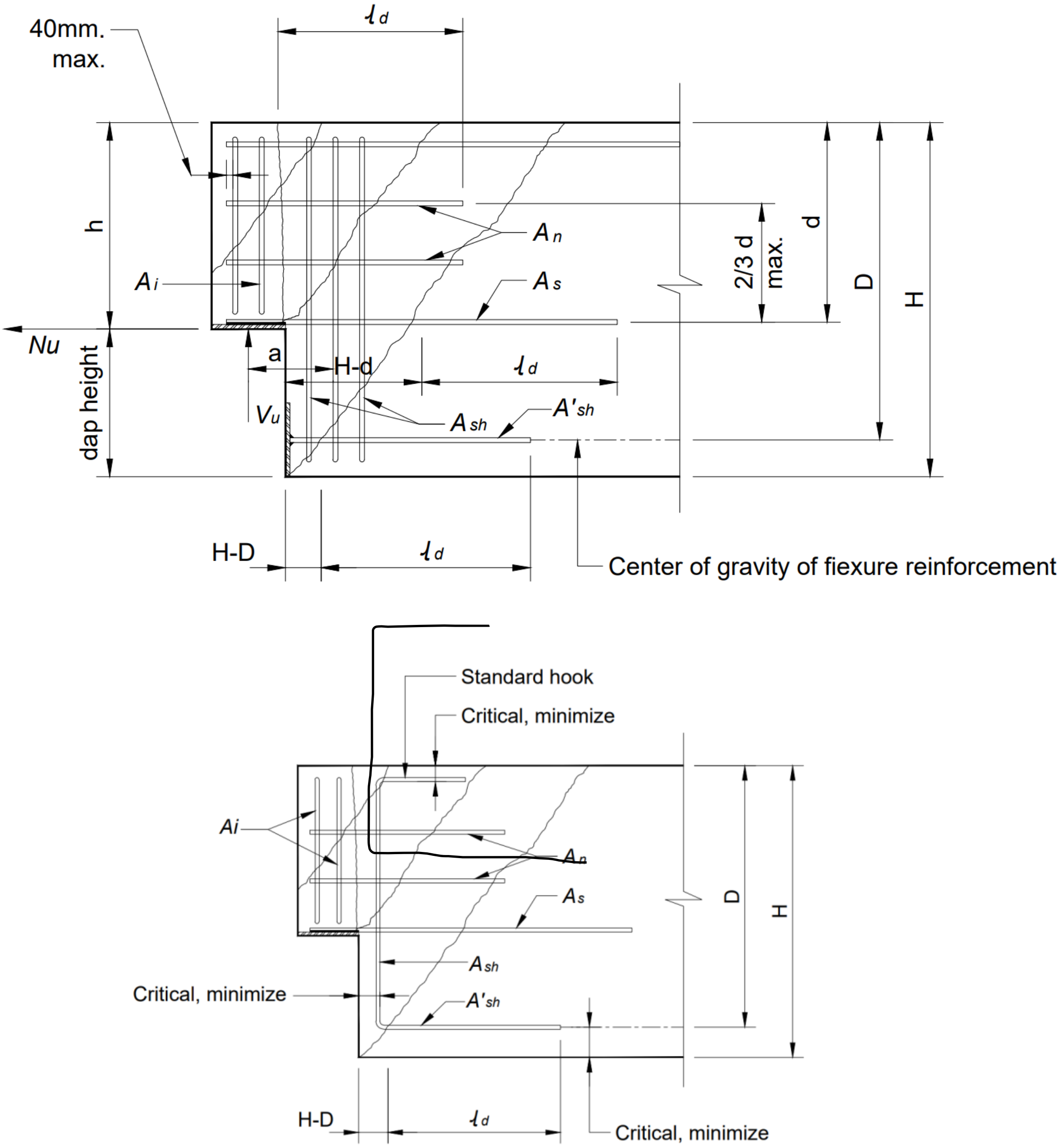


FIG. 22 POTENTIAL FAILURE MODES AND REQUIRED REINFORCEMENT IN NON-THIN STEMMED DAPPED ENDS

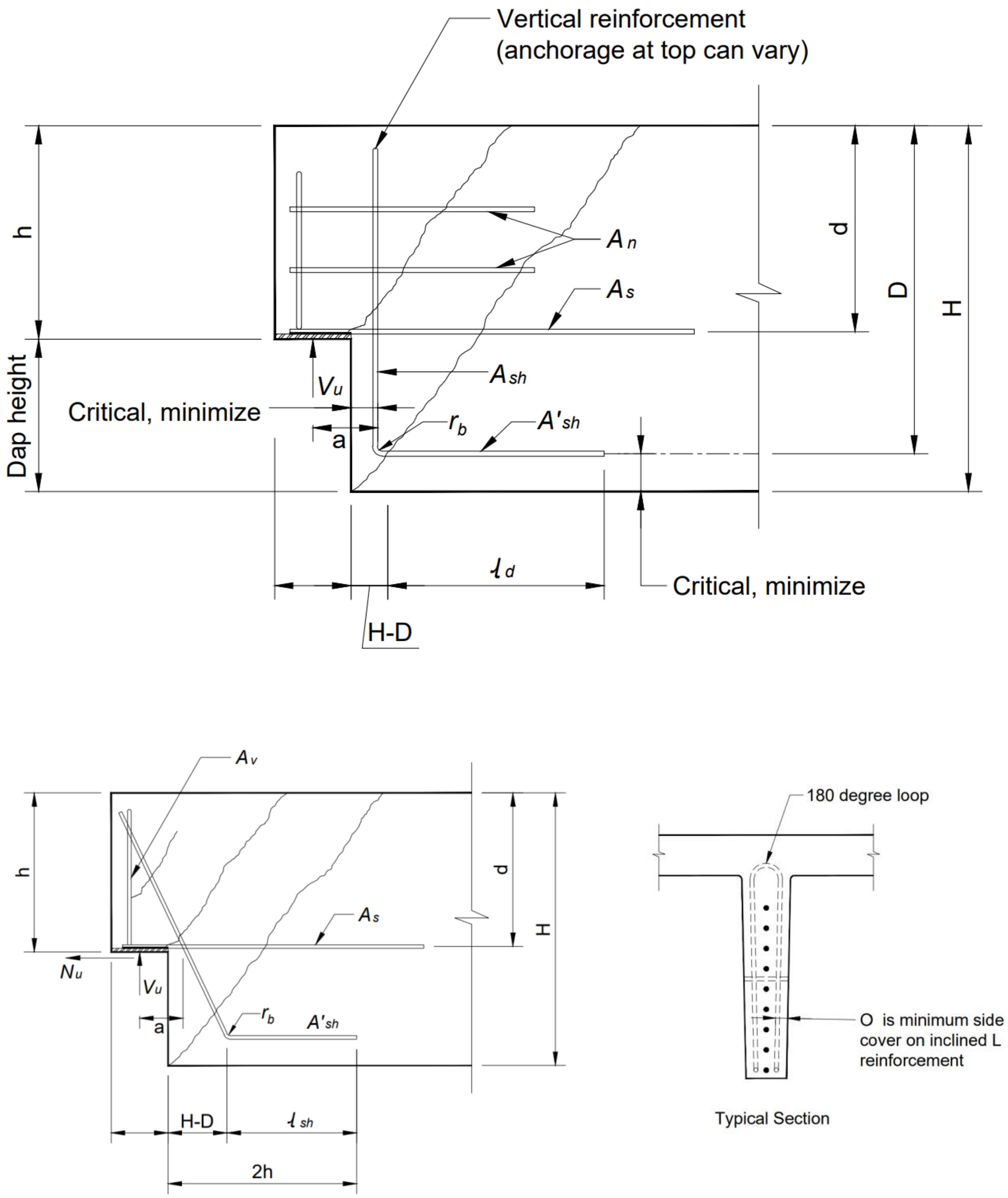


FIG. 23 POTENTIAL FAILURE MODES AND REQUIRED REINFORCEMENT IN THIN-STEMMED DAPPED ENDS

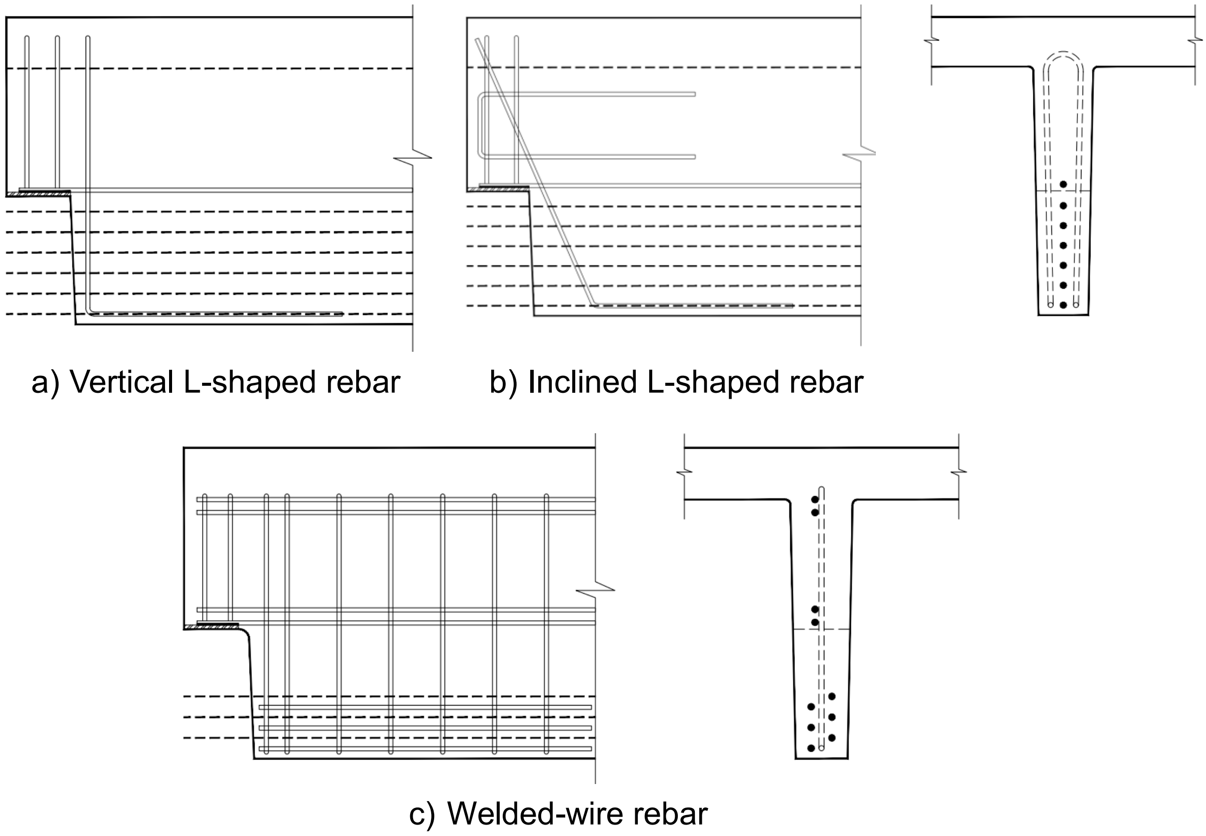


FIG. 24 CONFIGURATION OF DAP REINFORCEMENT FOR THIN-STEMMED DAPPED ENDS

5.11.15.7 The area of horizontal reinforcement A_s (area of reinforcement for flexure and axial tension in the extended end) shall be calculated using Equation 4. The values of A_f, A_n shall be calculated as per **5.11.17** and value of A_{vf} as per **5.12**.

$$A_s = A_f + A_n$$

or

$$A_s = \frac{2}{3} A_{vf} + A_n$$

Equation 4 (larger of the two)

5.11.15.8 The area of horizontal reinforcement A_h (area of direct shear reinforcement) shall be provided in the nib to arrest Crack 2 as per the following and shall be distributed within 2/3 d measured from the primary tension reinforcement A_s.

$$A_h = 0.5(A_s - A_n)$$

Equation 5

5.11.15.9 The area of hanger reinforcement A_{sh} shall be provided to arrest Crack 3, shall be as per the following.

$$A_{sh} = \frac{V_u}{0.75 f_y}$$

Equation 6

5.11.15.10 The area of vertical shear reinforcement A_v shall be provided to arrest Crack 4 as per the following:

$$V_{uR} = 0.75(A_v f_y + A_h f_y + 0.15\sqrt{f_{ck}}bd)$$

$$\text{Minimum } A_v = \frac{1}{2f_y}(1.34V_u - 0.15\sqrt{f_{ck}}bd) \qquad \text{Equation 7}$$

5.11.15.11 The anchorage of reinforcement shall be done as per the following

a) Horizontal bars A_s shall be extended a minimum of L_d beyond Crack 5 and anchored at the end of the component by welding to cross bars, plates, or angles.
b) Horizontal bars A_h shall be extended a minimum of L_d, beyond Crack 2 and anchored at the end of the component by hooks or other suitable means.
c) To ensure development of hanger reinforcement A_{sh}, the rebar shall be bent and continued parallel to the bottom of the component, or a separate horizontal anchored reinforcement with A'_{sh} >= A_{sh} shall be provided. The extension of reinforcement (A'_{sh}) at bottom of the component must be at least L_d beyond Crack 5. The A'_{sh}, reinforcement may be anchored on the dap side by welding it to a plate, angle, or cross bar.
d) The beam flexure reinforcement may also be used to ensure development of A_{sh} reinforcement, provided that the flexural reinforcement is adequately anchored on the dap side and the A_{sh} reinforcement is wrapped around the flexural reinforcement.
e) In thin-stemmed components, it is recommended that the extension of the hanger reinforcement be greater than L_d. A'_{sh} shall extend a distance that is the greater of 1.5L_d of the strand past the face of the dap or 2.0L_d of A'_{sh}. beyond the diagonal crack 5.
f) Vertical reinforcement A_v should be properly anchored by hooks, as required by good practice [6-7(3)].
g) Thin-stemmed components, except for the vertical "Z" configuration, which has the bar welded to the plate, should have at least one 12 mm diameter rebar welded to the bearing plate or equivalent development length (L-rebar).
h) Welded-wire reinforcement in place of bars may be used for reinforcement. It should be anchored in accordance with good practice [6-7(3)]. In thin-stemmed components the use of welded-wire reinforcement should be limited to situations where it is placed symmetrically in the width of the stem.

5.11.15.12 *Other considerations*

In addition to the reinforcement for the dapped end, it is important that the following items be considered:

a) The depth of the extended end should not be less than about one half the depth of the beam, unless the beam is deeper than necessary for other than structural reasons.
b) The hanger reinforcement A_{sh} should be placed as close as practical to the re-entrant corner and as symmetrically as possible around the centroid of the section being considered. This reinforcement requirement is not additive to other shear-reinforcement requirements but should be in addition to torsion reinforcement.

c) The shear strength of the full-depth beam behind the dap must be verified.
d) For thin-stemmed components. for a distance of 2H beyond the dap the concrete contribution to shear strength should be limited to

$$V_c = 0.15\sqrt{f_{ck}}b_w d_p$$

or

$V_c = 0.15\sqrt{f_{ck}}b_w d_p$ where at least two bonded strands in the extended end are present — Equation 8

Where,

b_w is the average width of the stem for the full depth of the section
d_p is the distance from the top to the centroid of the prestressing strand for the full depth section and shall not be less than 0.8H

e) For thin-stemmed components, for a distance 2H beyond the dap, the reinforcement contribution to shear strength V_s shall be limited as per the following

$$V_s = 0.15\sqrt{f_{ck}}b_w d_p \quad \text{Equation 9}$$

5.11.16 *Ledges*

5.11.16.1 *General*

Beam and wall ledges (as shown in Figure 25) shall be designed as per the following guidelines. Hanger steel requirements for the ledge in a wall need not be satisfied except where penetrations occur just below ledges. The design procedure explained in this section shall be applicable for the following cases:

a) $N_u \leq V_u$
b) Ledges with heights of 200 to 450 mm.
c) Ledge projections of 150 to 250 mm.
d) Bearing widths of components on the ledge ranging from 100 to 300 mm.
e) Distances of end load to end of ledge ranging from 100 to 900 mm.
f) Design concrete compressive strengths f_{ck} of 30 to 80 MPa.

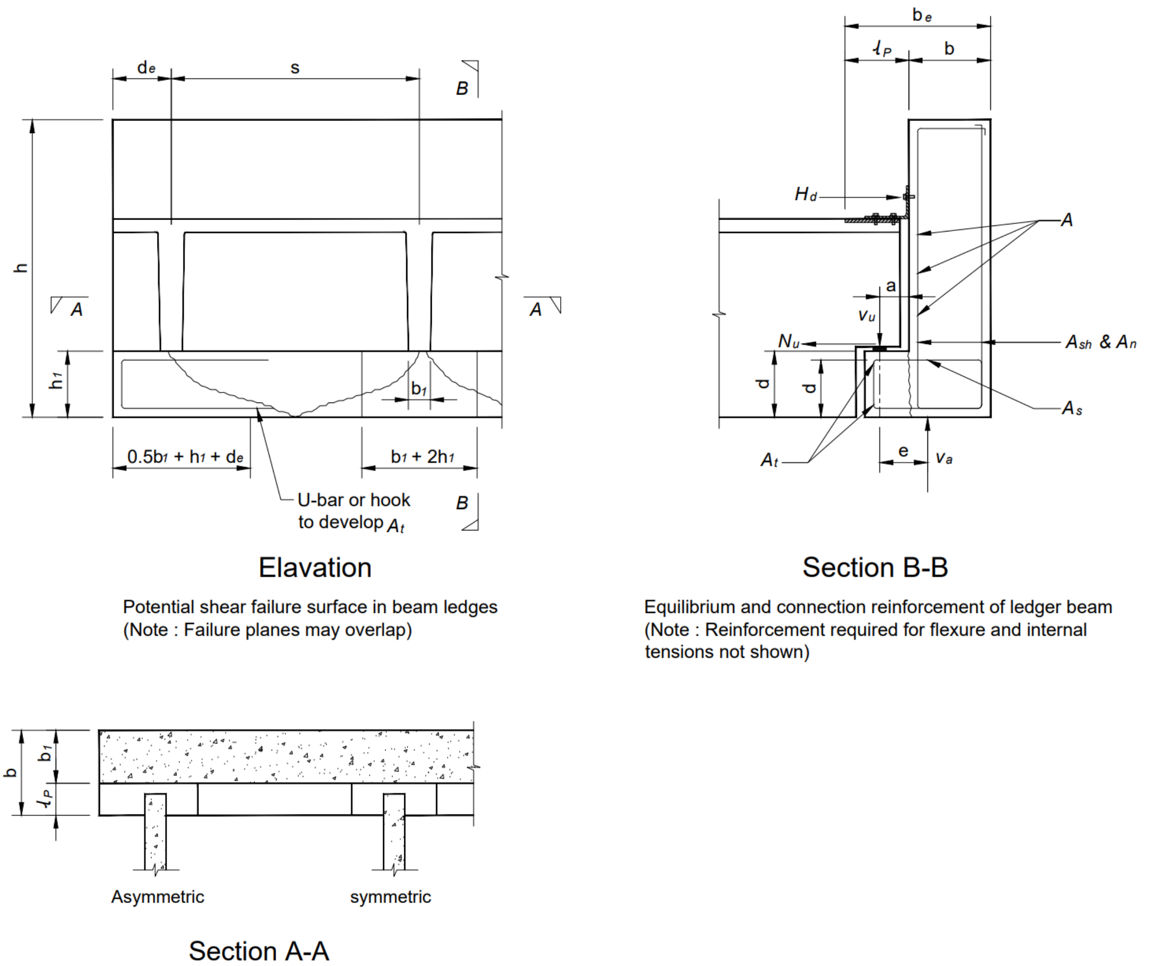


FIG. 25 DESIGN OF BEAM LEDGES

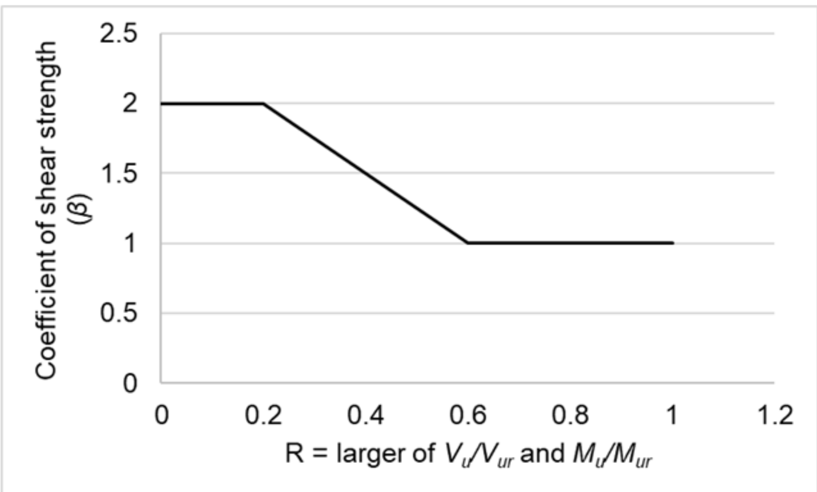


FIG. 26 COEFFICIENT OF SHEAR STRENGTH (β)

5.11.16.2 Shear strength of ledge for concentrated loads, not near the ends, where $d_e \geq 0.5b_t + h_l + l_p$, a symmetric failure controls the design punching shear strength of the ledge shall be determined as the lesser of following two equations.

$$V_{uR} = 0.056\gamma\beta\sqrt{f_{ck}}h_l(b_t + 2h_l + 2l_p)$$

or

$$V_{uR} = 0.028\gamma\beta\sqrt{f_{ck}}h_l(b_t + 2h_l + s + 2l_p)$$

Equation 10 (lesser of the two)

For concentrated loads that are near ends, where $d_e \leq 0.5b_t + h_l + l_p$, an asymmetric failure controls the design punching shear strength of the ledge shall be as per the following.

$$V_{uR} = 0.056\gamma\beta\sqrt{f_{ck}}h_l(0.5b_t + h_l + d_e + l_p)$$

or

$$V_{uR} = 0.56\gamma\beta\sqrt{f_{ck}}h_l(0.5b_t + h_l + d_e + l_p)$$

Equation 11 (lesser of the two)

Where,

h_l is the height of beam ledge
l_p is the length of ledge projection
b_t is the bearing width
s is the minimum spacing of concentrated loads
d_e is the distance from centre of load to the end of the ledge
β is the coefficient of shear strength based on R (as per Fig. 26)
$\gamma = \sqrt{1 + 12.5\frac{f_{pc}}{f_{ck}}}$, a factor for the effect of prestressing, 1 for precast beams
f_{pc} is the average prestress force after losses divided by gross concrete area of beam

5.11.16.4 For ledges supporting a continuous load or a series of closely spaced concentrated loads, punching shear strength per metre run shall be determined as per the following.

$$V_{uR} = 0.675\sqrt{f_{ck}}h_l$$

Equation 12

5.11.16.5 If the applied factored load exceeds the strength as determined above, the ledge shall be designed for shear transfer and diagonal tension in accordance with **5.11.15.8** through **5.11.15.10**.

5.11.16.6 Transverse (cantilever) bending of the ledge requires flexural reinforcement ($A_s = A_f + A_n$), shall be computed using **5.11.17.5**. Such reinforcement shall be uniformly spaced over a width of $6h_l$ on either side of the bearing, but not to exceed half the distance to the next load. Bar spacing shall not exceed the ledge depth h_l or 450 mm.

5.11.16.7 Longitudinal reinforcements shall be placed in both the top and bottom of the ledge portion of the beam and calculated as per the following:

$$A_l = \frac{200l_pd_l}{0.75f_y}$$

Equation 13

d_l is the design depth of A_l reinforcement in Fig. 25

5.11.16.8 Hanger steel A_{sh} shall be computed using following equation and distributed in the web of the beam. The reinforcement shall be uniformly spaced over a width of $6h_l$ on either side of the bearing, but not to exceed half the distance to the next load. The area of reinforcement shall not be additive to shear and torsional reinforcement.

$$A_{sh} = \frac{Vu}{0.75 f_y}(m)$$

m for L beam

$$m = \frac{(d_s + a) - (3 - 2\frac{h_l}{h})(\frac{h_l}{h})^2 \left(\frac{b_l}{2}\right) - e\gamma_t \frac{x_l^2 y_l}{(x_l^2 y_l + x_w^2 y_w)}}{d_s} \geq 0.6 \qquad \text{Equation 14}$$

m for inverted tee-beam

$$m = \frac{\left(\frac{b}{2} + e\right) - (3 - 2\frac{h_l}{h})(\frac{h_l}{h})^2 \left(\frac{b}{2}\right) - e\gamma_t \frac{x_l^2 y_l}{(x_l^2 y_l + x_w^2 y_w)}}{d_s} \geq 0.4$$

Where,

b_l is the width of web plus ledge being designed
d_s is the distance from outside face of web to A_{sh} reinforcement
γ_t = 0 when closed ties are not used in the ledge
γ_t = 1, when closed ties are used in the ledge
x_l, y_l, x_w, y_w, are defined in Fig. 27

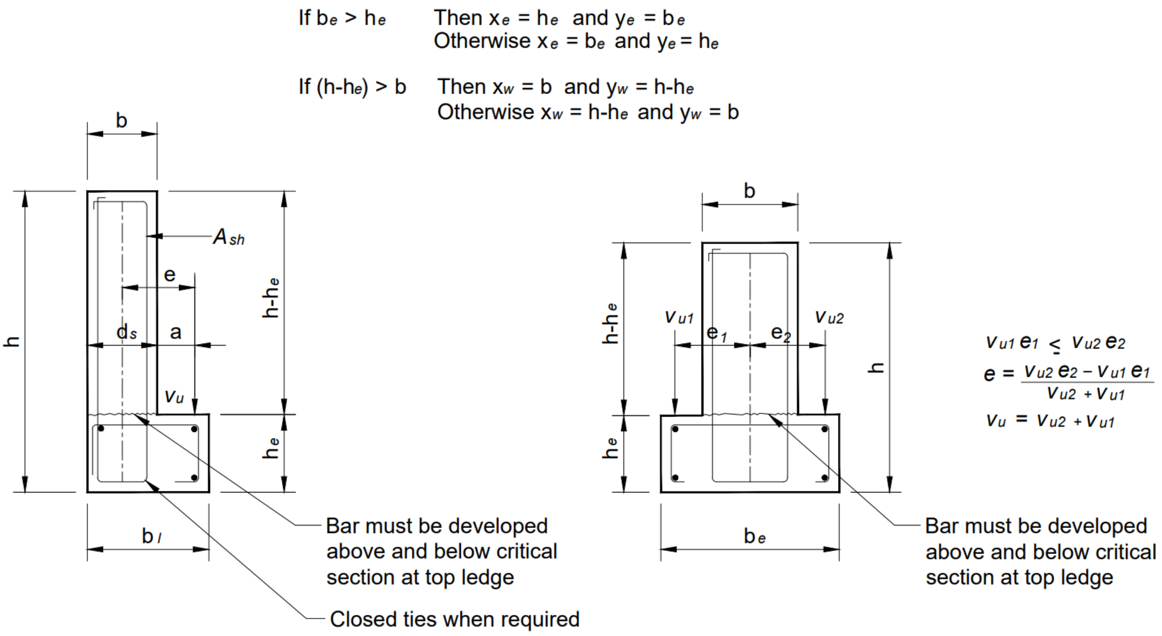


FIG. 27 LEDGE HANGER STEEL GEOMETRY

5.11.17 *Concrete Corbels*

5.11.17.1 *General*

Concrete corbels are short cantilevers that support other components and transmit the load to the supporting component and tend to act as simple trusses or deep beams (*see* Fig. 28).

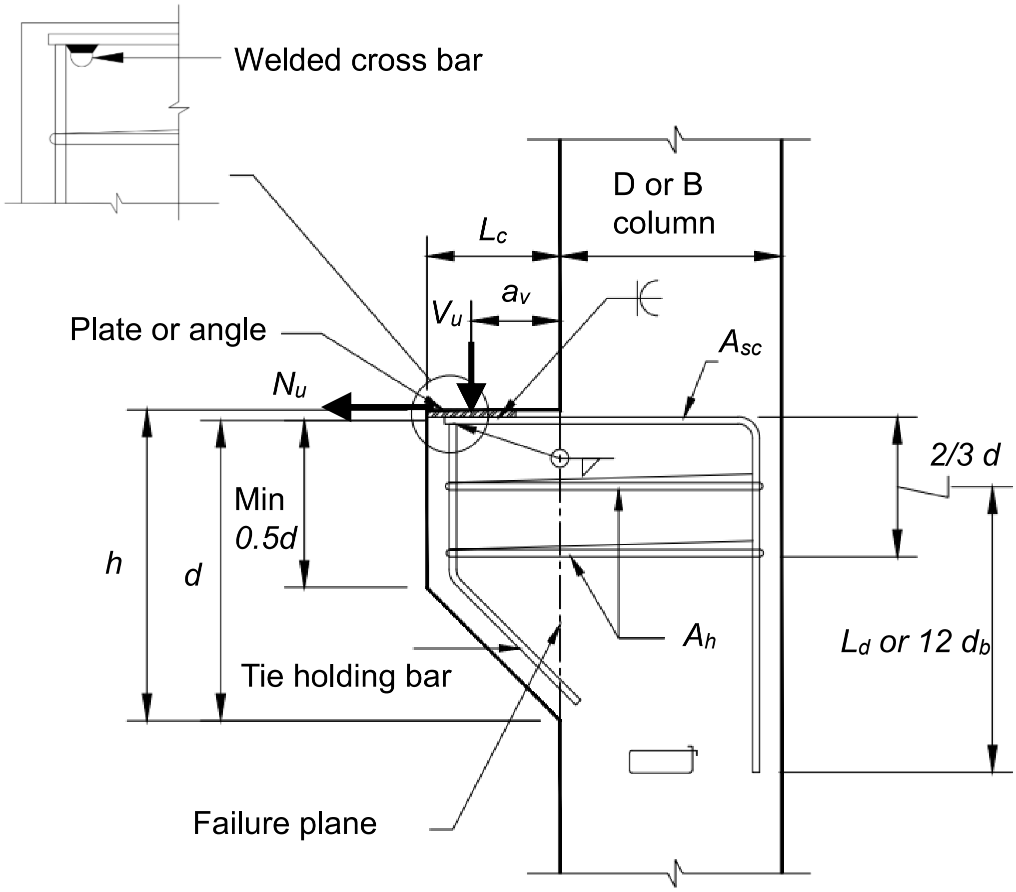
5.11.17.2 The design based on strut and-tie method shall be as per good practice [6-7(3)]. For steel brackets, good practice [6-7(33)] shall be referred.

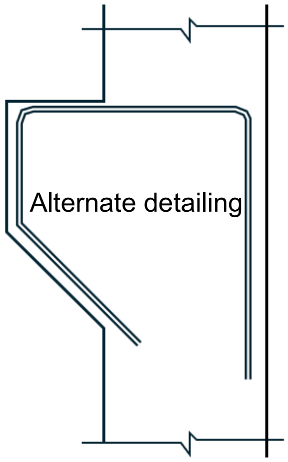
5.11.17.3 The cantilever beam method of designing a corbel presented in this section shall be used according to following limitations

a) $a_v/d <=1$

b) $N_u <= V_u$

5.11.17.4 The dimensions of a corbel shall be selected such that the nominal shear strength shall not exceed the strength calculated as per Table 6.





1) The main rebar for A_{sc} should be extended beyond the critical section and developed into the supporting member.
2) Welded bar or alternate detailing shall be followed for the outside free edge.
3) Horizontal closed ties shall be used for A_h

FIG. 28 DESIGN OF CONCRETE CORBELS

5.11.17.5 The area of primary tension reinforcement A_{sc} shall be greater of (A_f+ A_n) and (2/3) A_{vf}+ A_n

5.11.17.6 The area of reinforcement A_f shall be calculated as per the following equation.

$$A_f = \frac{V_u a_v + N_u(h-d)}{0.7 f_y d} \quad \text{Equation 15}$$

5.11.17.7 The area of reinforcement A_n shall be calculated as per the following equation.

$$A_n = \frac{N_u}{0.75 f_y} \quad \text{Equation 16}$$

5.11.17.8 The area of reinforcement A_{vf} shall be calculated as per shear friction (*see* **5.12**).

5.11.17.9 Unless tensile forces are prevented from being applied to the bracket or corbel, N_u shall be considered as $0.2V_u$ or as specified in the project.

5.11.17.10 If bearing pads are used to avoid tensile forces, the value of N_u that corresponds to the force causing the pad to slip shall be considered.

5.11.17.11 Minimum reinforcement (A_{sc}) shall be calculated as per the following equation. Where the corbel depth is larger than required by design a reduced depth d may be used consistently in all the design equations.

$$A_{sc,min} = 0.032 \frac{f_{ck}}{f_y} bd \quad \text{Equation 17}$$

5.11.17.12 The area of stirrups (A_h) shall be calculated as per the following equation.

$$A_h \geq 0.5(A_{sc} - A_n) \quad \text{Equation 18}$$

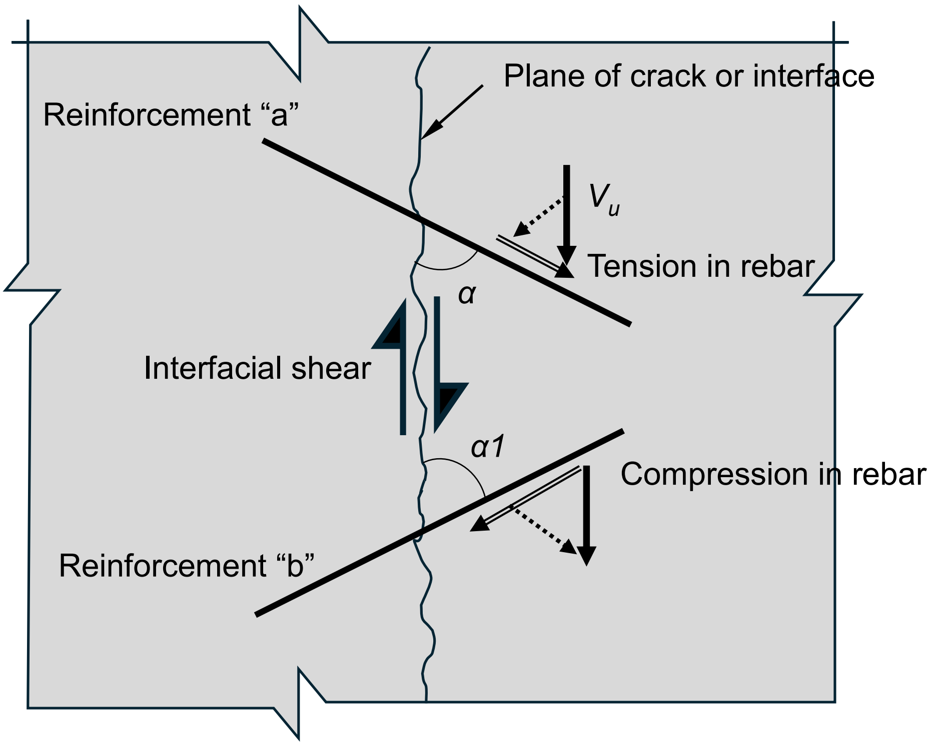
5.11.17.13 The shear reinforcement shall be provided as closed stirrups and uniformly distributed within 2/3 d measured from the primary tension reinforcement.

5.11.17.14 The development length for primary tension reinforcing bar shall be as per good practice [6-7(3)]. Development length for tension reinforcement shall be measured from the assumed failure plane (face of the supporting member). For member not having enough embedment length, hooked bars shall be used.

5.11.17.15 The main tension steel within the concrete corbel shall be developed at the outer edge of the corbel by welding to a cross bar, bearing plate with cross bar, angle section or bending along the depth of corbel.

5.12 Shear Friction

Shear friction shall be applied to consider shear transfer across interface between dissimilar materials or interface between concrete cast at different time or across a shear plane as shown in Fig. 29, reinforcement “a”. The following clauses shall be used.



NOTE – Reinforcement "a" shall be considered in shear transfer and reinforcement "b" shall be neglected.

FIG. 29 SHEAR FRICTION REINFORCEMENT

5.12.1 *Nominal Shear Strength*

5.12.1.1 Value of V_{uR} across the assumed shear plane shall be calculated using Equation 19 or Equation 20 depending on the angle of shear reinforcement.

5.12.1.2 If shear-friction reinforcement is perpendicular to the shear plane, nominal shear strength across the assumed shear plane shall be calculated by:

$$V_{uR} = 0.75 \mu A_{vf} f_y \qquad \text{Equation 19}$$

5.12.1.3 If shear-friction reinforcement is inclined to the shear plane and the shear force induces tension in the shear friction reinforcement, nominal shear strength across the assumed shear plane shall be calculated by:

$$V_{uR} = 0.75 \, A_{vf} f_y \, (\mu \sin \alpha + \cos \alpha) \qquad \text{Equation 20}$$

Where,

A_{vf} is the area of reinforcement crossing the assumed shear plane to resist shear,
μ is the coefficient of friction in accordance with Table 5,
α is the angle between shear-friction reinforcement and assumed shear plane

Table 5 Coefficient of Friction
(*Clause* 5.12.1.3)

Sl No.	Contact surface condition	Coefficient of friction
(1)	(2)	(3)
i)	Concrete placed monolithically	1.4
ii)	Concrete placed against hardened concrete that is clean, free of laitance, and intentionally roughened to a full amplitude of approximately 6 mm	1.0
iii)	Concrete placed against hardened concrete that is clean, free of laitance, and not intentionally roughened	0.6
iv)	Concrete placed against as-rolled structural steel that is clean, free of paint, and with shear transferred across the contact surface by headed studs or by welded deformed bars or wire	0.7

5.12.2 The value of V_{uR} across the assumed shear plane shall not exceed the limits in Table 6. Where concretes of different strengths are cast against each other, the lesser value of f_{ck} shall be used in Table 6.

Table 6 Maximum VuR across the assumed shear plane
(*Clause* 5.12.1.4)

Sl No.	Surface Condition	Maximum V_{uR}	
i)	Concrete placed monolithically or placed against intentionally roughened surface (amplitude of 6 mm or more)	$= 0.12 f_{ck} A_{cr}$ $= (2.475 + 0.049 f_{ck}) A_{cr}$ $= 8.25 A_{cr}$	Equation 21 Least of three
ii)	Other cases	$= 0.12 f_{ck} A_{cr}$ $= 4.125 A_{cr}$	Equation 22 Least of two

5.12.3 The frictional component of compression load (if any) present at the interface shall be considered along with the shear friction capacity.

5.12.4 Shear friction capacity shall not be considered for a joint producing compression in the joint reinforcement as shown in Fig. 29 reinforcement "b".

5.13 Serviceability Design Checks

5.13.1 *Deflection*

The relevant Clauses of good practice [6-7(3)] shall be followed for deflection calculations and limits. Partial fixity provided by the structural topping and nominal connections may be considered for serviceability checks.

5.13.2 *Crack*

The relevant Clauses of good practice [6-7(3)] shall be followed for crack width calculations and limits.

5.13.3 *In-Service Considerations*

The relevant Clauses of good practice [6-7(3)] shall be followed for service consideration calculations and limits.

5.14 Design of Demoulding, Handling Systems and Temporary forces

5.14.1 *Demoulding Forces*

Forces on the elements during lifting from the casting bed due to suction or adhesion between the precast elements and the mould should be accounted while deciding the strength of concrete. These are accounted for by applying an equivalent load factor to the self-weight of the member and treating it as an equivalent static force to evaluate the stresses in the precast element. Table 7 gives recommended minimum values of equivalent load factor for demoulding forces for different product types and finishes.

Table 7 Recommended Load Factors to Account for Demoulding of Elements
(*Clause* 5.14.1)

Sl No.	Product type	Finish	
		Exposed aggregate with retarder	Smooth mould (form oil only)
(1)	(2)	(3)	(4)
i)	Flat with removable side forms. No formed rebates or reveals	1.2	1.3
ii)	Flat with removable side forms. Formed rebates or reveals	1.3	1.4
iii)	Fluted with proper draft	1.4	1.6
iv)	Sculptured	1.5	1.7

NOTES

1 These factors are to be applied to the flexural design of precast elements only. For lifting inserts, refer to Table 10

2 The above values are recommended values only. Guidance should also be sought from the precast manufacturer based on their pre-casting experience if the load factors need to be increased.

3 The associated imposed loads or wind loads, if any, are to be assessed and considered under the appropriate load combination.

5.14.2 *Handling Stresses*

Precast units should not be inflicted with any permanent damage arising from their handling, storage, transportation and erection. Consideration should be given during design to loads on erected elements at construction stage and demoulding, storage, transportation and erection of precast units on site. Minor cracks (crack width less than the design requirement), if any shall be suitably repaired as per the contract guidelines or chemical manufacturer guidelines.

5.14.3 *Handling and Transportation*

An allowance should be made for dynamic loads and impact forces arising during handling, transportation, and erection. Similar to demoulding force consideration, Table 8 gives recommended values for equivalent load factor to be applied to the self-weight of members to allow for these forces.

Table 8 Recommended Load Factors to Account for Dynamic Forces Arising During Handling, Transportation and Erection

(*Clause* 5.14.3)

Sl No.	**Stage**	**Load factor**
(1)	(2)	(3)
i)	Yard handling	1.2
ii)	Transportation	1.5
iii)	Erection	1.2

NOTES

1 These factors are to be applied to the flexural design of precast elements only. For lifting inserts, refer to

2 The above values are recommended values only. Under certain conditions higher factors may apply i.e. certain unfavourable load conditions.

3 The associated imposed loads or wind loads, if any, are to be assessed and considered with the appropriate load combination.

5.14.4 *Early Demoulding/Handling of Precast Element*

For precast elements lifted and handled prior to gaining full strength the elements together with any lifting inserts should be designed accordingly. Recommended minimum concrete strengths for lifting and handling of precast elements are given in Table 9. Precast elements should be designed, using these lower strengths, to span between lifting points without excessive cracking or deflection. For prestressed concrete, consideration should also be given to stresses resulting from transfer of prestressing forces.

Table 9 Recommended Minimum Concrete Strength for Lifting and Handling
(*Clause* 5.14.4)

Sl No.	**Application**	**Minimum Concrete Strength** N/mm^2
(1)	(2)	(3)
i)	None specified, fine controlled crane, non-prestressed	10*
ii)	Lifting which involves significant impact or high acceleration	15*
iii)	All units where concrete strength for lifting is specified in the specification	As specified
iv)	Concentrically prestressed elements (piles, wall panels, or thin floor slabs)	20
v)	Eccentrically prestressed (T beam, deep flowing units)	25
vi)	Highly stressed prestressed elements	30 or as specified
	*Depending on anchor length or as recommended by insert manufacturer	

5.14.5 *Temporary Stages/ Erection Sequence*

The design of precast elements at temporary stages can be critical compared to the permanent stages. Consideration should be given to the loading imposed on the precast elements during each phase of construction. The following shall be verified,

a) Precast sections of composite elements which are required to support self-weight plus construction load prior to casting of an in-situ topping;
b) Lower precast floor slabs or precast stair flights which support propping to upper levels during installation; and
c) Bearing or halving joints which support higher temporary construction loads because of back propping to upper levels.

The design should also take into consideration that the structural action and framing might be different during the temporary stages resulting in higher stresses in individual members.

5.14.6 *Lifting Inserts*

The number of lifting inserts and location of inserts shall be decided by the following,

a) Lifting insert capacity (safe working load);
b) Total weight of the element;
c) Strength of concrete at age of lifting;
d) Shape of the unit;

e) Location of the inserts so that the failure of any one insert does not cause failure of the entire lifting system thereby ensuring the element can still be safely supported;
f) Position of any cut-outs and/or openings; and
g) Rigging arrangement.
h) Anchorage of inserts

All lifting inserts shall be designed by accounting the factors of safety given in Table 10. Typically lifting inserts shall be designed with a factor of safety of 4.

Table 10 Recommended Factors of Safety for Lifting Inserts
(*Clause* 5.14.6)

Sl No.	**Item**	**Recommended factor of safety**
(1)	(2)	(3)
i)	Bracing members	2
ii)	Bracing connections	3
iii)	Bracing inserts cast into precast members	3
iv)	Lifting inserts, normal circumstances	4
v)	Lifting inserts, multiple usage	5
vi)	Rebar inserts, single usage	2
vii)	Rebar inserts, multiple usage	4

5.14.7 *Bracing Design*

Bracing should be designed for both construction and wind loading. The construction load should be a minimum value of 1.5 kN/m² but should be increased if considered appropriate.

Wind loads should be calculated in accordance good practice [6-7(24)] and the bracing shall be designed for it.

6 JOINTS AND CONNECTIONS

6.1 Definition

A joint shall be considered based on the action of force transfer (tension, compression, shear, moment, etc.) at an interface (one or many) between the precast components. A connection which is a zone that includes various joints shall be designed in combination of any of the following forces:

a) Compressive force
b) Tensile force
c) Shear force
d) Bending and torsional moments

6.1.1 *Transfer of Compressive Force*

6.1.1.1 The precast or CIS member supporting the other elements shall be designed for the compressive forces generated by various load combination.

6.1.1.2 The joint shall be designed for all other forces arising from the external forces along with the predominant compression. Shear forces more than 0.1 P_u (axial load) shall not be neglected in the design of the joint.

6.1.1.3 The members may rotate because of temperature change, creep and shrinkage, hence bearing pads or strips shall be provided to account for the rotation. Minimum thickness of the joint shall be decided based on tolerance requirements, however, shall not be less than 5mm and more than 40 mm.

6.1.1.4 Appropriate edge distance for the bearing pad shall be provided to avoid crushing or cracking of edges.

6.1.1.5 Connection having bearing materials harder than concrete shall be checked for ultimate limit state as per good practice [6-7(3)]. Busting reinforcement shall be provided in the supporting member, if required.

6.1.1.6 Connection having bearing materials softer than concrete shall be checked for serviceability limit states as per good practice [6-7(3)]. Splitting reinforcement shall be provided in the supporting member, if required.

6.1.1.7 Joint using steel inserts for connection shall be properly designed and executed as per the design requirements. The steel components shall be anchored to the concrete members for proper transfer of compressive forces to the main reinforcement.

6.1.1.8 Connections shall be provided with reinforcement as follows or with equivalent connection.

a) For walls elements, dowels shall be placed at a maximum spacing of 450 mm or as required by design. Also, at least two extreme edge dowels shall be continuous from foundation till roof using Type 2 coupler or any other connection;
b) For column minimum four corner bars of 12 mm diameter shall be provided or as per design requirements;
c) For beam at least one 16 mm dowel at centre of the bearing region of the beam shall be provided to avoid accidental failure;
d) For any other member appropriate reinforcement shall be provided to avoid accidental lateral loads.

6.1.2 Transfer of tensile forces

6.1.2.1 Tensile forces generated at the joint shall be resisted by tie bars sufficiently anchored at both the sides of the joint.

6.1.2.2 Adhesive bond between the members shall not be accounted in force transfer.

6.1.2.3 The tensile stresses generated in the connecting members shall also be linked to the reinforcement of the member by proper provision of ties or any other connection.

6.1.2.4 Premature brittle failure shall be avoided for tie members and material selected for making tie shall be ductile.

6.1.2.5 A joint with grout filled tubes shall be utilised with proper development length. For calculation of development length bond strength of grout shall be used. If no test results are available, the bond strength of grout shall be considered as the tensile strength of grout material.

6.1.2.6 A joint using bolting, welding or lap splicing shall be properly anchored to the precast components and transfer of forces in the member shall be verified.

6.1.2.7 Reinforcement loops (U-bars) protruding from precast elements may be used to provide tie between the elements as shown in Fig. 30. Reinforcement of 10 mm or higher diameter shall be provided as longitudinal reinforcement (preferably four numbers with U-bars) as shown in the figure to avoid premature brittle failure of the joint. Lap length, spacing of loop bars and overlapping length shall be as per the figure.

6.1.2.8 Anchoring of reinforcement shall be such that high stress concentration in the members are avoided.

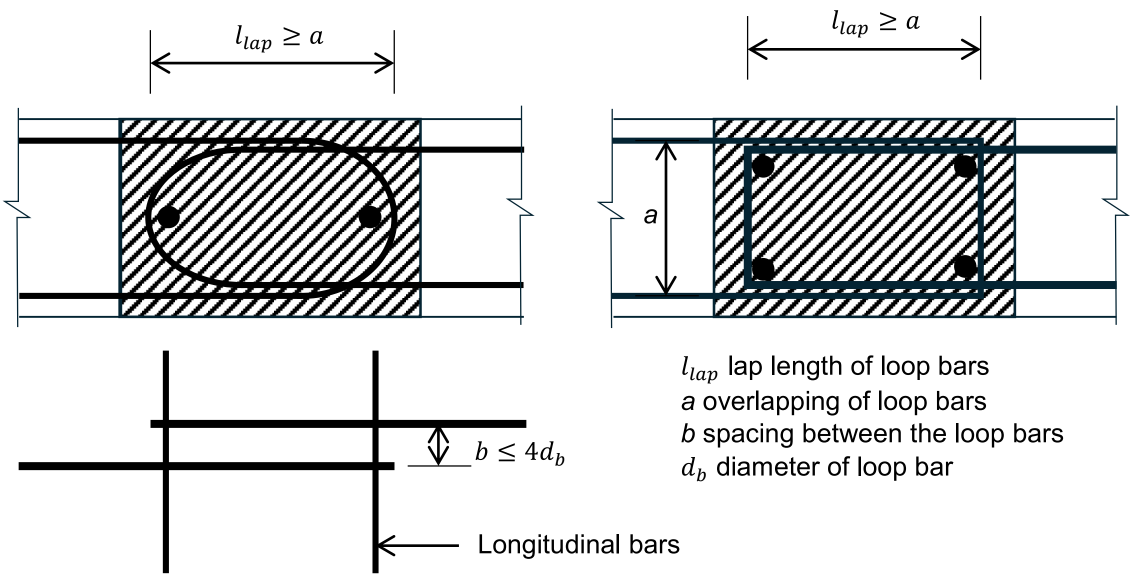


FIG. 30 REINFORCEMENT LOOP JOINT FOR TRANSFERRING TENSION

6.1.3 *Transfer of Shear Force*

6.1.3.1 Shear forces may be transferred between concrete elements by adhesion or friction at joint interfaces, shear-key effect at indented joint faces, dowel action of transverse steel bars, pins and bolts, or by other mechanical connection devices. The frictional resistance can be enhanced by the pullout resistance of tie bars properly placed across the joint.

6.1.3.2 Adhesive bond or adhesion between the interfaces of elements shall not be considered for calculation of shear strength of the joint.

6.1.3.3 Shear resistance of joint between two elements with reinforcement may be calculated using shear friction (**5.12**) equation or as per good practice [6-7(3)]. Shear friction shall not be used if the reinforcement crossing the joint is subjected to compressive forces by the displacement of the members.

6.1.3.4 Permanent compressive stresses acting on the joint shall also be considered along with shear friction.

6.1.3.5 Unreinforced shear keys or castellation or indented joint face shall be used for members subjected to very high shear forces. This connection shall be designed to remain elastic under ultimate limit states to avoid sudden brittle failure of the joint. Transverse reinforcement across the interfaces shall be provided to prevent sudden separation of the members.

6.1.3.6 The dimension of shear keys shall be as per Fig. 31.

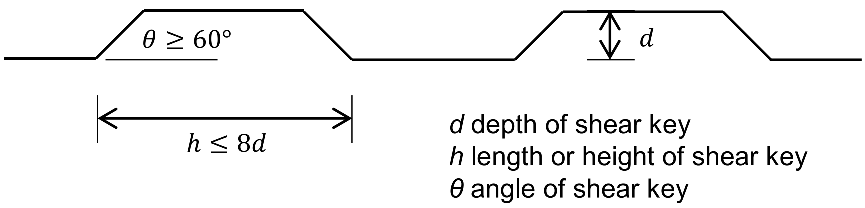


FIG. 31 DETAILING OF SHEAR KEY WITHOUT REINFORCEMENT

6.1.4 *Transfer of Bending and Torsional Moment*

6.1.4.1 Strong connections shall be used possessing stiffness, strength and ductility confirming to that of CIS construction.

6.1.4.2 Moment resisting connections shall be designed such that ductile failures will occur without any local modes of brittle failure (shear, pull-out, etc.).

6.1.4.3 Continuity within the joint may be obtained by any of the following or combination;

a) Lapping of bars
b) Reinforcement grouted into apertures
c) Overlapping loop or U-bars
d) Reinforcement connected using threaded couplers
e) Any other type of connection with appropriate testing of the connection

6.2 Connection based on Precast Concrete Seismic Systems

The connection of seismic moment resisting frames and structural walls incorporating precast concrete elements generally fall into two broad categories, either "equivalent monolithic (emulative)" systems or, "jointed" systems. The distinction between these types of construction is based on the design of the connections between the precast concrete elements as provided in the following sections.

6.2.1 *Equivalent Monolithic Systems (emulative)*

A precast concrete structural system satisfying the requirements of this clause shall have strength and toughness equivalent to that provided by a comparable monolithic reinforced concrete structure.

6.2.1.1 *Connections in monolithic systems*

The connections between precast concrete elements of equivalent monolithic systems can be subdivided into two categories:

a) *Strong connections of nominal ductility*

   In moment resisting frames and structural walls these connections are protected by a capacity design approach which ensures that flexural yielding occurs away from the connection region;

b) *Ductile connections*

   Ductile connections of equivalent monolithic systems typically comprise longitudinal reinforcing bars in the connection which are expected to enter the post-elastic range in a severe earthquake.

   In moment resisting frames yield penetration may occur into the connection end-region. The potential plastic hinge region may extend a distance along the end of the member as in cast-in-place construction.

6.2.2 *Jointed Systems*

In jointed systems the connections are weaker than the adjacent precast concrete elements. Jointed systems do not emulate the performance of cast-in-place concrete construction. The post-elastic deformations of these systems during an earthquake are typically concentrated at the interfaces of the precast concrete elements where a crack opens and closes. This system shall be used with approvals from competent authorities and testing to demonstrate the performance.

6.2.2.1 *Connections in jointed systems*

The connections between precast concrete elements of jointed systems can be subdivided into three categories. These connections shall be used with appropriate testing and approval of competent authorities.

a) *Connections of limited ductility*

Connections of limited ductility in jointed systems are usually dry connections formed by welding or bolting reinforced bars or plates or steel embedment's and dry-packing and grouting. These connections do not behave as if part of a monolithic construction and generally have limited ductility.

An example of a jointed system with connections of limited ductility involving structural walls is tilt up construction. Generally, such structures should be designed for limited ductility or nominally ductile behaviour;

b) *Ductile jointed connections*

Ductile connections of jointed systems are generally dry connections in which unbonded posttensioned tendons are used to connect the precast concrete elements together. The non-linear deformations of the system are concentrated at the interfaces of the precast concrete elements where a crack opens and closes. The unbonded post-tensioned tendons remain in the elastic range. These connections have the advantage of reduced damage and of being self-centring (i.e., practically no residual deformation) after an earthquake;

c) *Ductile hybrid connections*

Hybrid systems shall have connections which combine both unbonded post-tensioned tendons and longitudinal steel reinforcing bars (tension/compression yield) or other energy dissipating devices (for example, flexing steel plates or friction devices).

6.3 Design of Connections

The design of connections shall follow those design methods and considerations for reinforced concrete, prestressed concrete and structural steel. Otherwise, the connection design shall be based on tests and approved from competent authority or academic institution. The following types are the broad category of the connections based on connecting members.

a) Column to foundation
b) Column to column
c) Beam to column
d) Beam to beam
e) Beam to slab
f) Wall to wall
g) Wall to slab
h) Slab to slab

Examples of typical connections are shown in Annex D. These connections are for illustrative purposes only. In all instances, the design should demonstrate that the connections are able to resist the applied structural actions. Where appropriate, the suitability of the connection to act as a pinned or moment connection is highlighted. The location of the connections for a framed structure shall be as per **4** (Figs. 2, 3, 4 and 5).

6.3.1 *Detailing of Reinforcement*

The following shall be considered:

a) *Lapping of bars* – Where bars passing through the connection are lapped to provide continuity of reinforcement, the recommendations good practice [6-7(3)] and integrity tie requirements shall be followed.

b) Reinforcement grouted into aperture – An adequate capacity should be provided for grouted reinforcing bars to prevent pullout. Embedment length shall be as per manufacturer guidelines, however testing shall be carried out as per **10**. If grouted tube is used, the embedment length of dowel shall be at least 300 mm or as required by design, whichever is higher.

c) *Reinforcement loops* – Loop reinforcement shall be provided as per **6.1.2** and good practice [6-7(3)].

d) *Couplers* – Reinforcement may be connected by couplers. The concrete cover to the couplers (other than grouted tube or duct) shall be at least 12 mm or as per specifications of the project. A locking device should be used for threaded coupler connections where there is a risk of the threaded connection working loose, e.g. during vibration of in-situ concrete. Reference should be made to [6-7(10)] and the manufacturers' technical specifications for guidance and acceptance criteria for the usage. Testing of couplers shall be as per **10** and relevant guidelines of [6-7(10)]. When the system is part of LLRS, the grout strength shall be 100 MPa.

e) *Welding of bars* – When bars are connected by welding, the connection shall ensure full capacity of the bar is achieved and failure of weld is avoided. Testing of the welded samples shall be as per relevant standards. Welding of rebar shall be avoided for normal circumstances, to be used for repair or strengthening of a connection, if required.

6.3.2 *Connections in Compression*

6.3.2.1 The connection in tension shall follow the guidelines of **6.1.1**.

6.3.2.2 In normal circumstances, the area of concrete to be utilised for calculating the strength of the connection in a wall or column should be the greater of:

a) 75 percent of the area of contact between the wall or column and connection; or

b) The area of the in-situ concrete excluding the part of any intruding slab or beam units However those parts of the floor slab or beam units that are solid over the bearing may be included in calculating the strength and such units should be properly bedded on concrete or mortar of adequate quality. This area should not be taken as greater than 90 percent of the wall or column area.

6.3.3 *Connections in Tension*

6.3.3.1 The connection in tension shall follow the guidelines of **6.1.2**.

6.3.3.2 Stirrups shall be placed along the lap length, for the connection utilising lapping of bars, grouted duct, grouted coupler for transfer of tensile forces.

6.3.3.3 Welding or bolting shall be used with appropriate design. The embedded inserts shall be appropriately anchored to the primary member.

6.3.4 *Connection in Shear*

6.3.4.1 The connection in tension shall follow the guidelines of **6.1.3**.

6.3.4.2 A shear connection may be considered effective, if the connection is grouted with a suitable concrete or mortar mix or strength at least 5 MPa higher than the connecting members and the criterial of **6.1.3** is satisfied.

6.3.4.3 For joints subjected to minimal shear between wall panels or thin members, looped wire ropes shall be used to connect between the members with a maximum spacing of 450 mm. These connections shall not be used in LLRS system and transfer of seismic forces.

6.3.4.4 Transfer of forces solely by friction caused due to gravity load shall not be used.

6.3.5 *Bond, Anchorage, Bearing, Laps, Joints and Bends in Bars*

6.3.5.1 Provision of bond, anchorage, bearing, laps, joints and bend in bars shall be as follows:

a) *Avoidance of bond failure due to ultimate loads* – At both sides of any cross-section the force in each bar should be developed by an appropriate embedment length or other end anchorage.

b) *Anchorage bond stress* – Anchorage bond stress (τ_b) is assumed to be constant over the effective anchorage length. It may be taken as the force in the bar divided by its effective surface anchorage area.

$$\tau_b = {F_s}/{\pi \varphi_E L} \qquad \text{Equation 23}$$

Where,

τ_b is the bond stress;
F_s is the force in the bar or group of bars;

L is the anchorage length;
φ_E is the effective bar size which, for a single bar is equal to the bar size and, for a group of bars

c) *Values for design ultimate anchorage bond stress* – Values for design ultimate anchorage bond stress τ_{bu} may be obtained from the equation. The anchorage bond stress (τ_b) shall not exceed the design ultimate anchorage bond stress.

$$\tau_{bu} = \beta\sqrt{f_{cu}} \qquad \text{Equation 24}$$

Where,

τ_{bu} is the design ultimate anchorage bond stress;
β is a coefficient dependent on the bar type.

The values of β may be taken from Table 11. These values include a partial safety factor (γ_m) of 1.4.

Table 11 Values of Bond Coefficient β
[*Clause* 6.3.4 (c)]

Bar type	β	
	Bar in tension	Bar in compression
Plain bar	0.28	0.35
Deformed bar	0.4	0.63

6.4 Connections Other than Those Involving Continuity of Reinforcement

6.4.1 *Joints with Structural Steel Inserts*

Joints with structural steel inserts generally consist of a steel plate or rolled steel section projecting from the face of a column to support the end of a beam. The reinforcement in the ends of the supported member shall be designed in accordance with the provisions mentioned in good practice [6-7(3)]. Detailed design provisions shall include the following:

a) The steel sections and any bolted or welded connections should be designed in accordance with the appropriate recommendations.
b) Design ultimate bearing stresses shall be as per **5.11**.
c) Consideration should be given in the design to the possibility of vertical splitting under the steel section because of shrinkage effects and localized bearing stresses, for example under narrow steel plate.

6.4.2 *Resin Adhesives*

Resin adhesives may be used to form joints subjected to compression but not to resist tension or shear. These adhesives should only be used where they are adequately protected against the effects of fire.

6.4.3 *Other Types of Connections*

Any other type of connection that can be shown to be capable of carrying the ultimate loads acting on it may be used. Amongst those suitable for resisting shear and flexure are those made by prestressing across the joint.

6.5 Structural Integrity and Progressive Collapse

Reinforcement and connections shall be detailed to tie the structure together effectively adequate structural integrity and to prevent progressive collapse. Integrity ties shall be followed in accordance with the following clauses. Figure 32 shows the typical arrangements of integrity ties in a large panel structure and frame structure. Progressive collapse requirements shall be as per **6.5.10**.

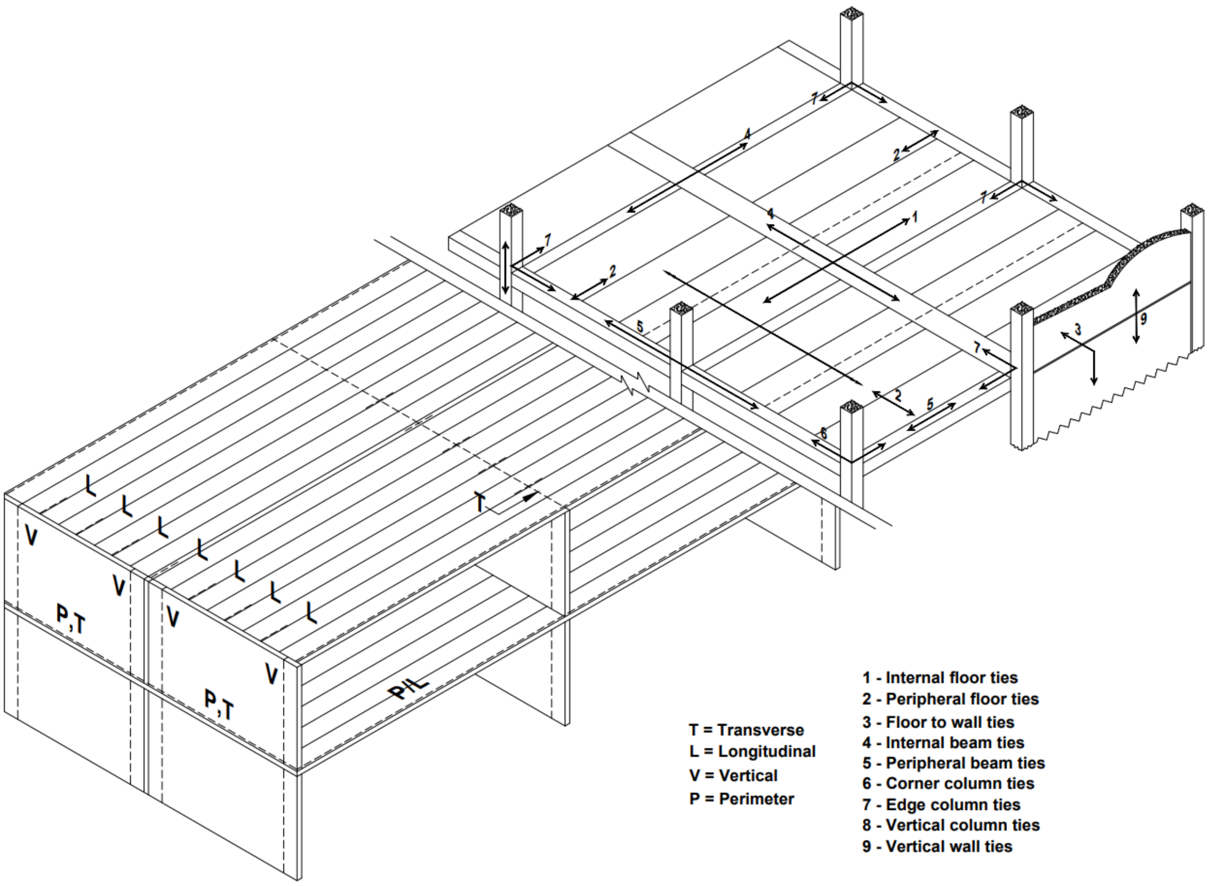
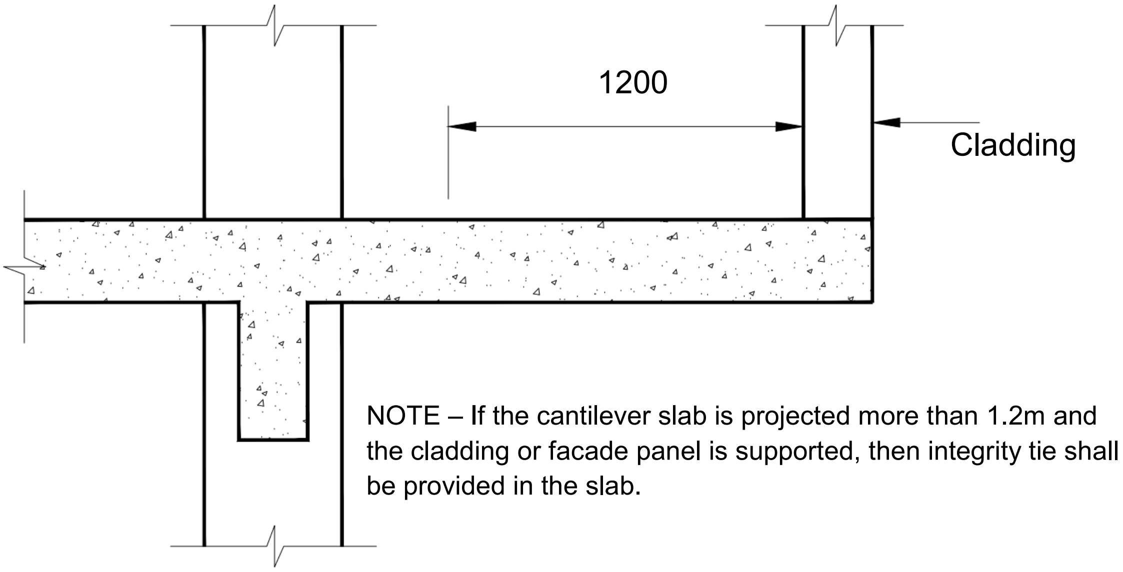


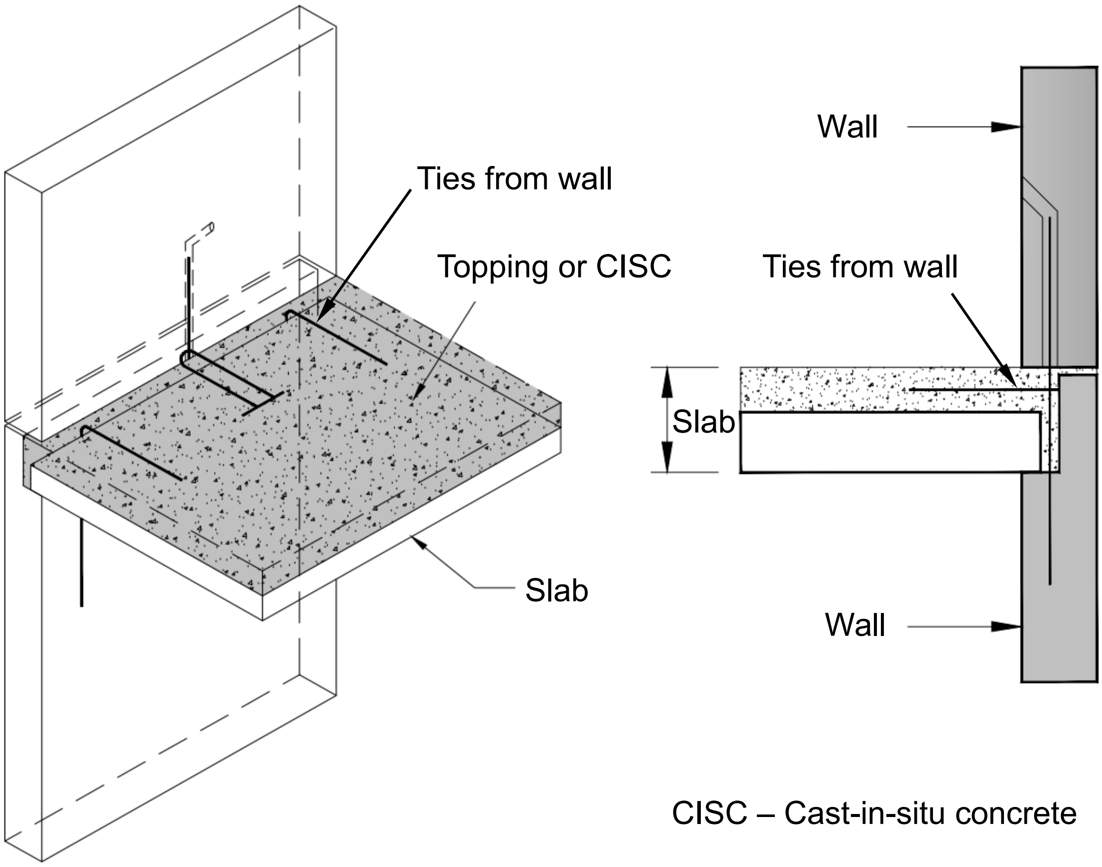
FIG. 32 TYPICAL ARRANGEMENT OF INTEGRITY TIES

6.5.1 *Peripheral Ties*

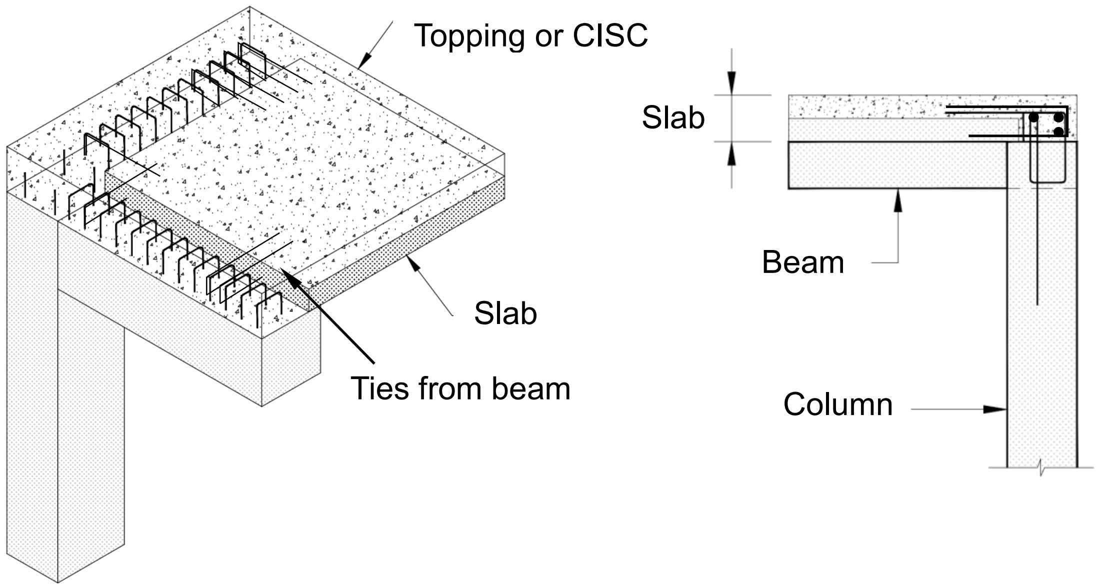
At each floor and roof level an effectively continuous tie shall be provided within 1.2 m of the edge of the building or within the perimeter wall (*see* Fig. 33). The tie shall be capable to resist a tensile force of F_t equal to 60 kN or (20 + 4N) kN, whichever is less, where N is the number of storeys (including basement).



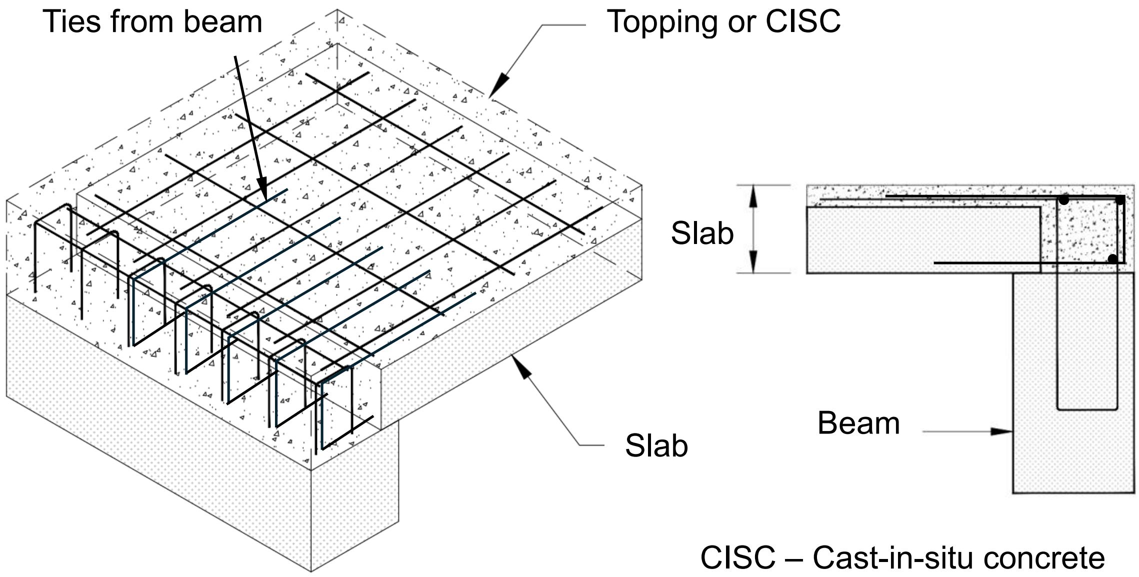
33A Position of Peripheral Tie



33B Precast wall to wall connection with sheathing pipe

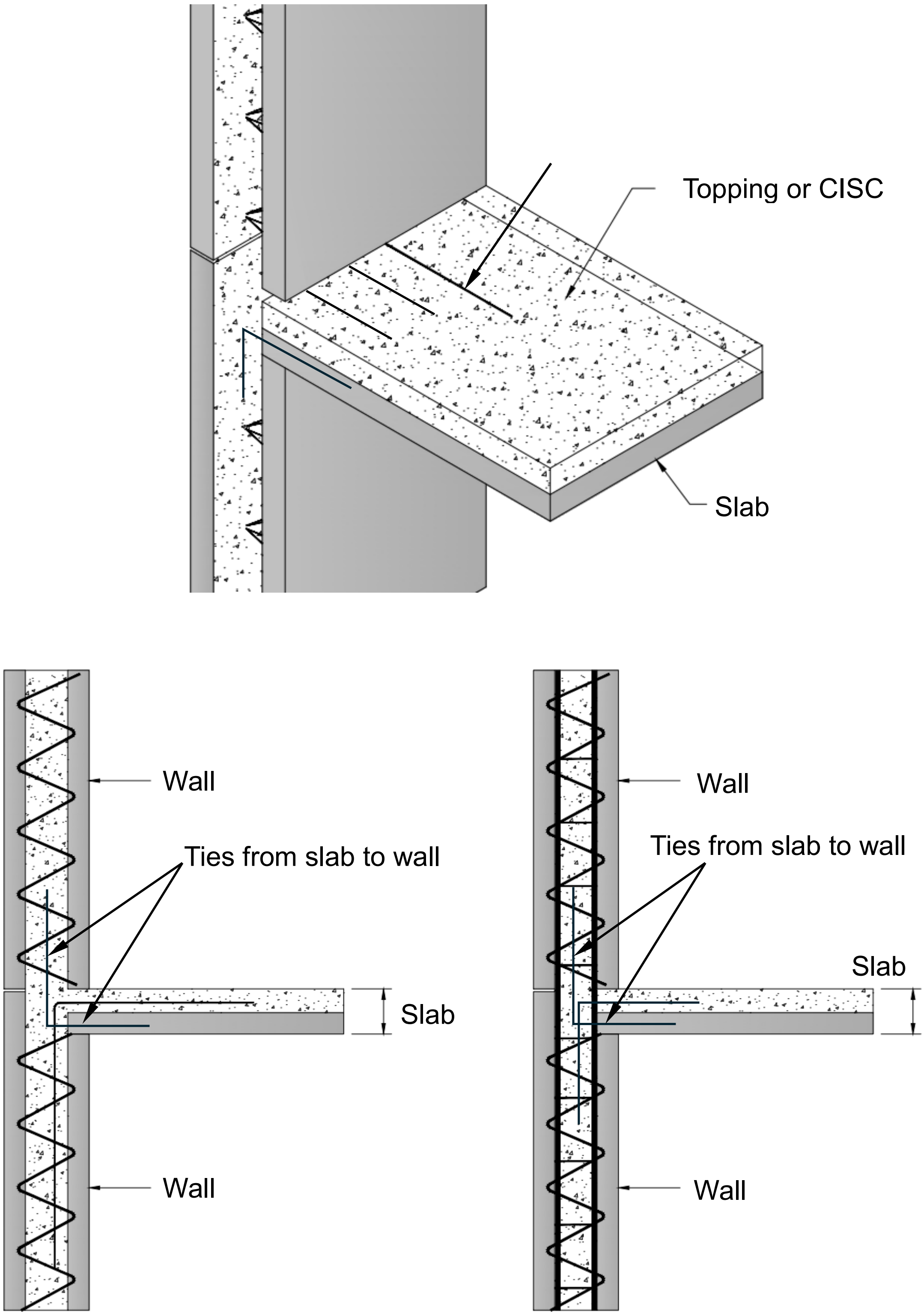


33C Precast column, beam and slab connection



CISC – Cast-in-situ concrete

33D Precast beam slab connection



CISC – Cast-in-situ concrete

33E Precast beam slab connection

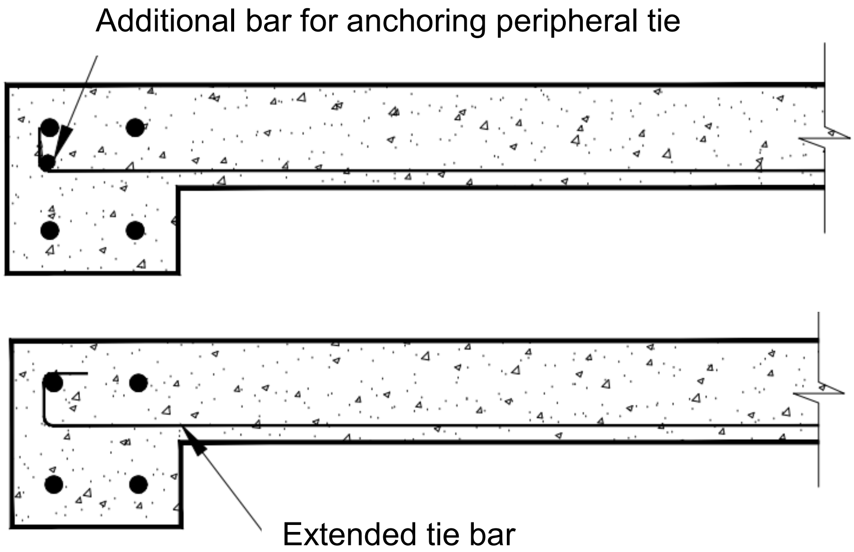
FIG. 33 POSITION FOR PERIPHERAL TIE

6.5.2 *Internal Ties*

These shall be provided at each floor and roof level in two directions approximately at right angles. Ties shall be effectively continuous throughout their length and be anchored to the peripheral tie at both ends, unless continuing as horizontal ties to columns or walls (*see* Fig. 34). The tensile strength, in kN/m width shall be the greater of:

$$\frac{g_k + q_k}{7.5}\frac{L_r F_t}{5} \text{ and } F_t \qquad \text{Equation 25}$$

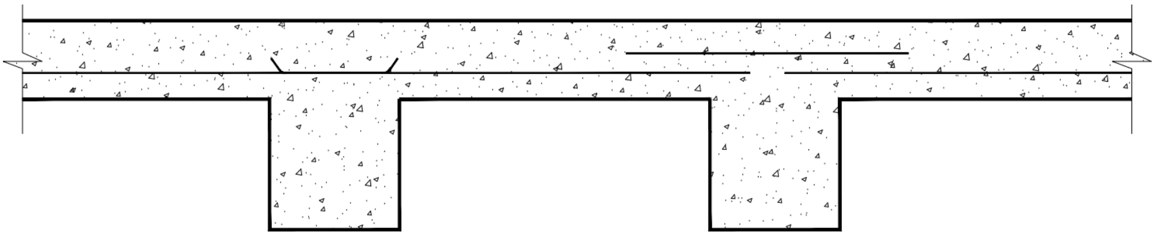
Where, (g_k + q_k) is the sum of average characteristic dead and imposed floor loads, in kN/m^2, and L_r is the greater of the distance between the centre of columns, frames or walls supporting any two adjacent floor spans in the direction of the tie under consideration.



NOTE – If the peripheral tie consists of bars in an edge beam, then the bottom bars in the slabs will not be at the same level as the peripheral tie bars. It is suggested that either an additional bar be used for anchoring in the peripheral tie or the internal tie bars be extended and anchored around the top bar in the beam.

FIG. 34 ANCHORING OF TIES IN SLABS

The bars providing these ties shall be distributed evenly in the slabs (*see* Fig. 35) or shall be grouped at or in the beams, walls or other appropriate positions but at spacing generally not greater than 1.5 L_r.



NOTE – For continuity in continuous slabs, bars are distributed evenly in a floor slab by means of lapping some bottom slab reinforcement at supports, either by extending existing bars or by an addition of splice bar.

FIG. 35 CONTINUITY REQUIREMENT FOR SLAB

6.5.3 *Horizontal Ties to Column and Wall*

All external load-bearing members such as columns and walls shall be anchored or tied horizontally into the structure at each floor and roof level. The design force for the tie shall be greater of:

a) $2F_t$ kN or $Ls \times (F_t /2.5)$ kN, whichever is less for a column or for each metre length, if there is a wall (*Ls* is the floor to ceiling height in metre).
b) 3 percent of the total ultimate vertical load in the column or wall at that level.

For corner columns, this tie force should be provided in each of two directions approximately at right angles.

6.5.4 *Vertical Ties*

Each column and each wall carrying vertical load should be tied continuously from the foundation to the roof level.

6.5.4.1 The reinforcement provided is required to resist a nominal tensile force of at least 50 kN per horizontal meter of wall.

6.5.4.2 At least two integrity ties shall be provided in each wall panel.

6.5.4.3 Connection between precast column shall have vertical integrity ties, with a nominal tensile strength of $1.4A_g$, where A_g is the gross area of the column. For column with larger cross section reduced effective area equal to the actual cross section required shall be used. However, the reduced area shall be at least one-half of the gross area of column.

6.5.4.4 In situation where provision of vertical ties cannot be done, the element should be removed, and the surrounding members shall be designed to bridge the gap.

6.5.4.5 All members participating in the LLRS shall have one tie continuous from foundation to terrace at each end of the member with Type 2 coupler (ties as per design) or direct lapping (ties as per lapping requirements).

6.5.5 *Tie Anchorage*

A tie crossing another tie at right angles may be considered anchored if the bars extend 12 times the bar diameter or an equivalent anchorage beyond the other tie; or an effective anchorage length, calculated from the tension force, beyond the centreline of the other tie. At abrupt changes in construction or at re-entrant corners, it shall be ensured that the ties are sufficiently anchored or to be made effective by other means.

6.5.6 *Continuity of Ties*

A continuous tie shall satisfy **6.3.1**. The minimum thickness of in-situ concrete section where tie bars are provided shall be at least the total dimension of the bar diameter (or two diameters at laps) and twice the maximum aggregate size plus 10 mm.

To provide continuity, the tie shall also satisfy one of the following:

a) A bar in a precast concrete unit lapped with a bar encased in in-situ concrete bounded on two opposite sides by rough faces of the same precast unit (*see* Fig. 36);

b) A bar in a precast concrete unit lapped with a bar encased in the topping of in-situ concrete tied to the precast unit by links or stirrups. The tensile resistance of such links and stirrups should not be less than the designed tension in the tie (*see* Fig. 37);

c) Bars lapped within in-situ topping concrete with projecting links or stirrups from the supporting precast units, such as beams or slabs (*see* Fig. 38);

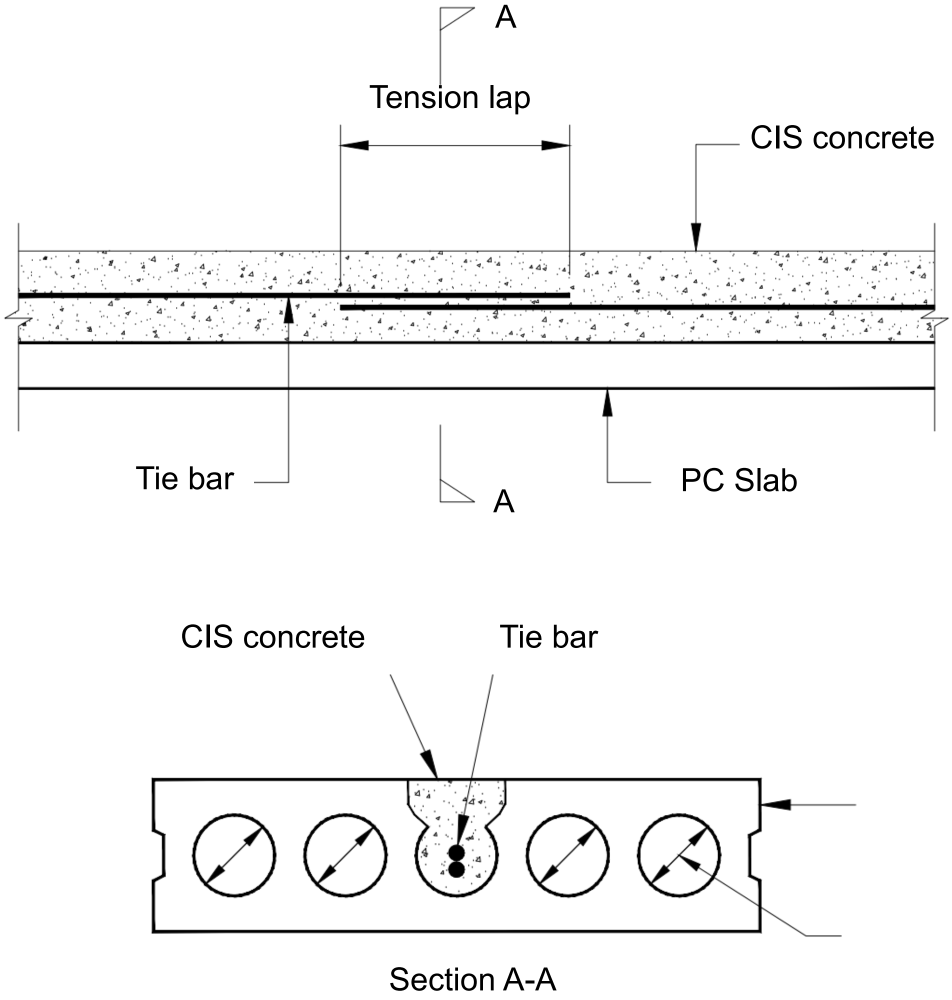


FIG. 36 CONTINUITY OF TIES: BARS IN PRECAST MEMBER LAPPED WITH BAR IN CIS

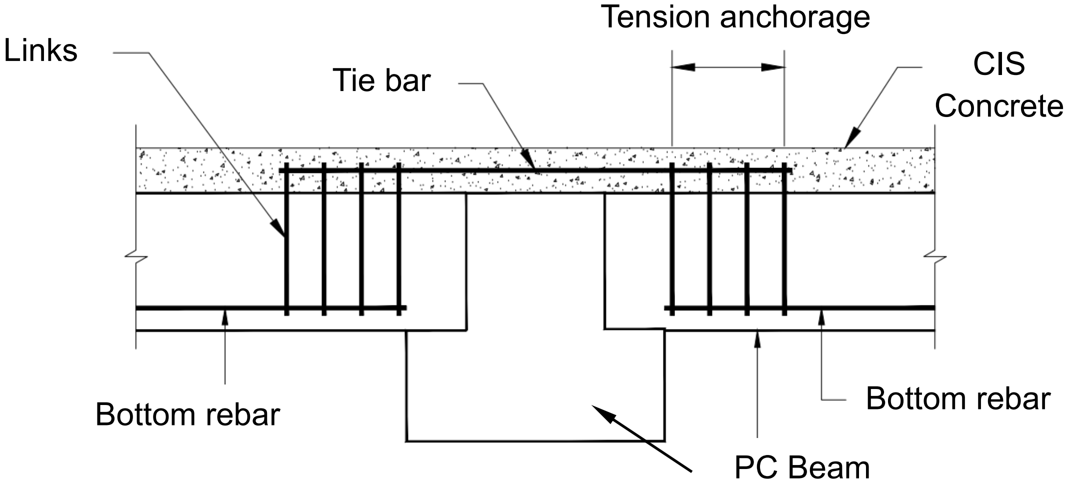


FIG. 37 CONTINUITY OF TIES: ANCHORAGE BY ENCLOSING LINKS

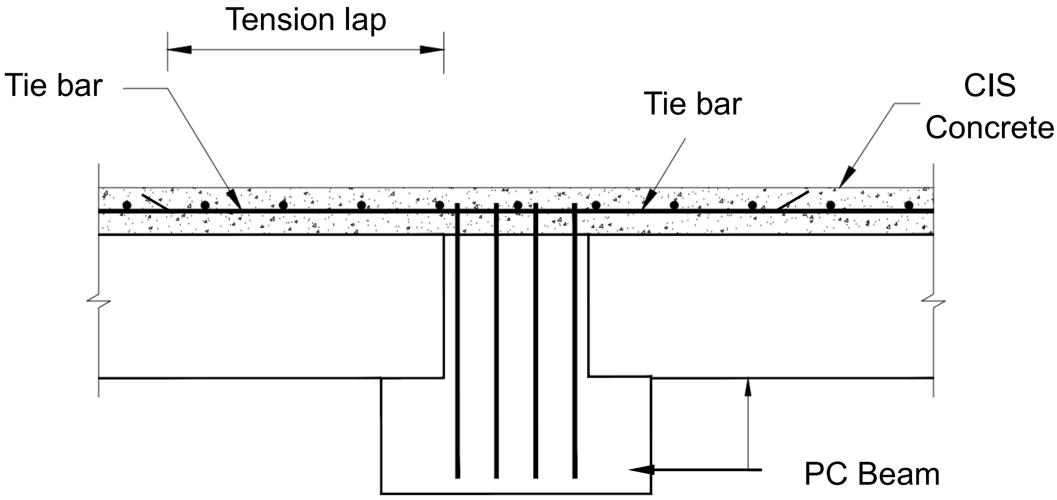


FIG. 38 CONTINUITY OF TIES: BARS LAPPED WITHIN IN-SITU CONCRETE

6.5.6.1 *Ties between Precast element and topping*

In potential plastic hinge regions, the consequences of delamination of the topping from the precast members shall be assessed. If the maximum shear stress at any section exceeds 0.4 MPa, connectors shall be provided between the topping and precast to achieve composite action as per the following guidelines:

a) Ties with an effective area of 40 mm^2 per m^2 of floor area, or equivalent connectors, shall connect the topping to the precast element;
b) Spacing of connectors shall not exceed 1 500 mm, and the tributary area of topping reliant on each connector shall not exceed 2.25 m^2;

c) Connectors shall engage horizontal reinforcement, or shall be otherwise effectively anchored into both the topping and the precast element, or into the joints between precast elements; and
d) In HCS appropriate connection shall be placed in slab joints.

6.5.7 *Anchorage in Structures*

All precast floor and precast roof units should be effectively anchored if these units are not utilised to provide the ties. The anchorage shall be capable of supporting the dead weight of the precast unit to that part of the structure which contains the ties.

6.5.8 Eccentricity

Ties connecting precast floor or roof units shall be so designed and placed as to minimise eccentricity.

6.5.9 Anchorage at supports

In case reinforcing bars are used to provide the structural integrity of slab ends supported on corbels or nibs, great care shall be taken to ensure it is adequately lapped and anchored. Allowance should also be made for constructional inaccuracies.

6.5.10 Progressive Collapse

The following recommendations shall be followed for ensuring stability of prefabricated structures:

a) Adequate strengthening of external joints of external wall panels is important since these elements are not fully restrained on both sides by floor panels. Adequate design precautions shall be taken by the designer. Connections for the external wall panels are likely to be the weakest points of a precast panel building, if not designed properly.
b) Restraint shall be provided to all load bearing elements at the corners of the building. These elements and the external ends of cross-wall units shall be stiffened either by introducing columns as connecting units or by jointing them to non-structural wall units, which in emergency shall act in force transfer.
c) In prefabricated construction, the possibility of gas or other explosions which can remove primary structural elements leading to progressive collapse of the structure shall be considered. It is, therefore, necessary to consider the possibility of progressive collapse in which the failure or displacement of one element of a structure causes the failure or displacement of another element and results in the partial or total collapse of the building.
d) Provision in the design to reduce the probability of progressive collapse is essential in buildings of height more than 15 m and is of relatively higher priority than for buildings of lower height. However, buildings of special importance shall be checked for progressive collapse irrespective of height guidelines. One way of preventing progressive collapse of external wall panels is to design the combined precast wall panels of entire width as a beam of depth equal to the floor height for the impact loading of upper floors and provide reinforcement accordingly at the top and bottom of all precast wall panels at each floor. To

make reinforcement continuous across joints, top and bottom bars projected into joints between wall panels shall be joined with lapping bars.

e) It is necessary to ensure that any local damage to a structure does not spread to other parts of the structure remote from the point of mishap and that the overall stability is not impaired, but it may not be necessary to stiffen all parts of the structure against local damage or collapse in the immediate vicinity of a mishap, unless the design briefs specially require this to be done. The requirements as specified at **6.5** shall be followed to prevent progressive collapse of the structure.

f) Additional protection may be required in respect of damage from vehicles. Further, it is necessary to consider the effect of damage to or displacement of a load-bearing member by an uncontrolled vehicle. It is strongly recommended that important structural members are adequately protected by concrete kerbs or similar method. In areas with possibility of passenger vehicular impact, the precast components shall be designed for an un-factored load of 27 kN, in any direction, acting at heights between 450 mm and 700 mm on an area not larger than 300 mm × 300 mm to produce maximum load effect. This load is not required to act concurrently with any handrail or guard rail system loads.

g) In all aspects of erection that affect structural design, it is essential that the designer shall maintain a close liaison with the builder/contractor regarding the erection procedures to be followed.

6.5.11 *Key Element*

For buildings of five or more storeys, the layout should be checked to identify key elements. A key element is, such that its failure would cause the collapse of more than a limited area close to it. The limited area defined above may be taken equal to 70 m^2 or 15 percent of the area of the storey, whichever is lesser. If key element exists, it is preferable to modify the layout so that the key element is avoided or design the element for a force of 36 kN/m^2.

6.6 Miscellaneous Items for Joints

6.6.1 *Sealants for Joints*

In choosing the appropriate type of sealant for the joints, consideration should be made in respect of the movements between the components to be joined, the bond that is achievable between the components and the sealant, and the nature of the sealing material itself. Hybrid, PU (polyurethane, polysulphide), silicon based or any other sealant shall be used depending on requirements.

6.6.2 *Joint Width*

Joint widths should be sized to accommodate construction tolerances, and the accommodation of movements without overstressing the jointing material. Irrespective of movement, a joint width of 5 mm is the minimum practicable for sealant application.

6.6.2.1 Minimum width of joint between the erected elements or supporting elements shall be as follows;

a) Minimum joint width shall be 10 mm, if not specified
b) 20 mm shall be for wall elements
c) 30 mm shall be for column elements
d) For larger elements as per grouting requirements but shall preferably not to exceed 50 mm

6.6.3 *Joint Preparation*

Satisfactory performance is critically dependent on the satisfactory adhesion of the sealant to the joint surfaces. Primers may be recommended by the manufacturer for some materials. Formwork oils, curing compounds, silicone waterproofing admixtures and surface coating materials may reduce bond and require special precautions.

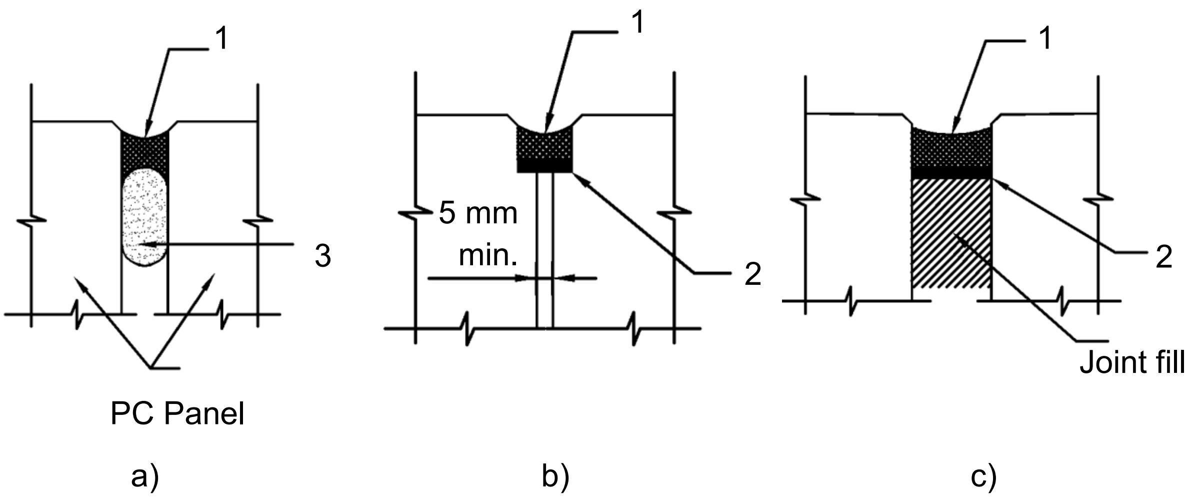
Water jetting, sand blasting, wire brushing or the use of retarder may be required to prepare the concrete joint surfaces in certain instances. Consideration should be given to the use of chamfers to reduce edge damage.

6.6.4 *Back up Material and Bond Breaker*

To ensure good adhesion, a firm backing should be provided for the application of sealants. The required shape and proportions of the sealant are achieved by the correct installation of the back up material.

Sealants in movement joints should not adhere to the backing material to avoid any unnecessary restraint. To ensure that the sealant and back up materials, bond breakers and joints fillers are compatible and appropriate for the proposed end use, advice from the manufacturer should be obtained as necessary.

The sealant backing may be provided by a closed cell foam back up material alone (*see* Fig. 39a), a thin self-adhesive bond breaker tape (*see* Fig. 39b) or a joint filler separated from the sealant by a thin self-adhesive bond breaking tape (*see* Fig. 39c).



1. Sealant, 2. Breaker tape or bond breaker, 3. Backer rod

FIG. 39 BACK-UP MATERIALS AND BOND BREAKERS IN MOVEMENT JOINTS

6.6.4.1 *Minimum joint gap widths*

For elastic sealants, the minimum thickness should be 5 mm, the ratio of width to thickness should never exceed 1:1 and for optimum performance 2:1.

6.6.4.2 *Sealant application*

High moisture content may be detrimental to the adhesion of the sealant. Sealing should not be undertaken if there is free water present on the surface of the concrete.

6.6.4.3 *Performance, choice and failure of sealant*

The magnitude of the movement, and also the mode, frequency and rate of movement affect the performance of a sealed joint.

There are many factors affecting the choice of sealant suitable for the different types of movement. However, as a general rule, joints which have to accommodate frequent and rapid movement need an elastic sealant, while joints in massive components, with high thermal inertia resulting in much slower movement, may be satisfactorily sealed with an elastoplastic, plasto elastic or a plastic sealant.

The different ways in which sealants can fail as a consequence of different factors including climatic conditions, environmental factors, substrate incompatibility, abrasion and traffic loading need to be considered when selecting a sealant.

6.6.5 *Sealing Strips*

Preformed sealing strips of appropriate sizes and sections shall be used as required. There are two basic types:

a) mastic strips; and
b) impregnated or coated cellular strips.

6.6.5.1 *Mastic strips*

These should be normally installed during the assembly of components. They require an initial compression to ensure proper adhesion to the components forming the joint. As a degree of compression is also required during in service, mastic strips should not be used for joints which open beyond their assembled size.

6.6.5.2 *Impregnated or coated cellular strips*

Impregnated or coated cellular strips may be supplied in a pre-compressed form, and one face may be adhesive coated. When pre-compressed, they can readily be installed within the joint gaps, but should be of a suitable size to be maintained under the degree of compression specified by the manufacturer throughout the range of joint movements. The degree of compression may be varied according to the level of sealing performance required.

To ensure uniformity of compression and stability of the seal, it is important that the joint faces are parallel. Sufficient joint depth shall be provided to accommodate the seal with these depths to width ratios. For external applications, sealing strips should have adequate exposure resistance for the proposed service conditions.

6.6.6 *Joint Fillers*

Fillers for movement joints should be carefully selected to suit their intended use. To ensure that the sealant and filler are compatible, advice from the manufacturer should be sought. Fillers should be non-absorbent with appropriate elastic properties and fire resistant.

6.6.7 *Overlapping of Precast Facade*
The resistance to water penetration between the upper and lower panel of precast facade is commonly provided by an upstand profile. A minimum overlap of 75 mm between the upper and lower panel is recommended.

7 PLANNING

7.1 Pre-Engineering and Design Coordination

7.1.1 *Importance of Pre-Engineering*

Pre-engineering plays a critical role in the planning and execution of any precast concrete project. To ensure a successful outcome, the planning engineer should begin working from the design stage to ensure proper production, installation, connections, and logistics. Key resources must be identified and prepared for each phase of the project, including:

a) Available land/approvals/water and electricity availability for a site-based factory
b) Suitable plant and machinery;
c) Steel moulds;
d) Lifting machinery at factory;
e) Trailers; and
f) Lifting machinery on site (tower cranes/ mobile cranes).
g) Site access for transportation of large elements as well as route studies and local regulations and hours for large trailers

7.1.2 *Resource Planning and Feasibility Factors*

The resources should be carefully planned based on the types of project elements and their quantities. The engineer is also responsible for reserving these resources throughout the project duration. Key feasibility considerations include:

a) *Building geometry* – Ensure shapes and geometry are as symmetrical and regular as possible;
b) *Grid-lines* – Column and wall locations should, preferably, follow a standardized pattern;

c) *Height clearances* – Consideration of clear height expectations between beams and slabs;
d) *Grid spacing* – Optimize grid spacing to take full advantage of precast elements; and
e) *Standardization* – Standardize elements within one floor and across multiple floors when feasible.

7.1.3 *Pre-Engineering Design Stage Process*

The pre-engineering design stage should include the following steps:

a) Study of building functionality
b) Load assumptions and calculations
c) Preparation of the design basis report (DBR)
d) Structural analysis
e) Preliminary framing plan selection for precast elements
f) Approval of preliminary framing plans by the architect/client
g) Review meetings with architects and consultants
h) Finalization of the structural framing plan after incorporating feedback and value engineering
j) Release of the good for construction (GFC) and structural framing plan (R0), including:
    1) Geometry of precast elements;
    2) General Arrangement (GA) drawings with reinforcement details; and
    3) Connections and inserts.
k) Coordination with Mechanical, Electrical, Plumbing, and other service consultants should occur during the early stages

7.2 Project Planning, Scheduling and Monitoring

7.2.1 *Production Planning*

Careful planning is essential for ensuring that precast concrete systems are produced efficiently. Key factors to address include:

a) Synchronization of manufacturing schedules and resources to meet construction and storage needs;
b) Anticipation of any special transportation or access challenges;
c) Use of detailed production shop drawings to facilitate smooth execution.
d) Factory curing periods for high strength concrete elements.

7.2.1.1 *Shop drawings*

Shop drawings should contain:

a) Member shapes (elevations and sections) and dimensions;
b) Details of reinforcement, anchors, inserts; etc.
c) Connection details;
d) Production tolerances;
e) Handling and lifting devices;

f) Finishing and bearing seat details;
g) Transportation and storage methods;
h) Unique identification of elements (ID, location, and orientation)

7.2.1.2 *Factory vs. on-site production*

Decide whether precast elements should be produced in an off-site factory or on-site, based on factors such as:

a) Project scale and volume**;**
b) Availability of factory space near the site;
c) Contractual agreements regarding space provision;
d) Element type, weight, and size;
e) Cost-benefit analysis.

7.2.2 *Production Schedule*

Cycle Time and Throughput Rate

a) *Cycle time* – refers to the total time to complete one production cycle of an element, from mould preparation to quality checks and delivery.
b) *Throughput rate* – refers to the rate of production (units per day, week, or month).

7.2.2.2 *Developing the production schedule*

To develop a production schedule:

a) Split the floor plan into various "installation parts," typically aligned with crane locations and capacities;
b) Estimate the number of elements per part and the installation duration for each part based on element type and connection complexity;
c) Use historical data and experience to estimate installation cycle times for each element;
d) Assign unique element IDs to each installation part and sequence them accordingly;
e) Publish a sequence chart that includes:
    1) Planned Drawing Release Date;
    2) Planned Casting Date;
    3) Planned Transportation Date; and
    4) Planned Installation Date

7.3 Project and Factory Logistics Planning

7.3.1 *Haulage Planning*

Transportation constraints influence the size and shape of precast elements. Consider the following factors:

a) Trailer lengths (standard lengths: 6 m, 12 m, with special cases up to 30 m);

b) Trailer width (typically between 2.4 m to 2.7 m);
c) Height clearance (3.6 m to 4 m, adjustable with low-bed trailers);
d) Weight capacity (25 MT to 35 MT);
e) Special permits for oversized loads may be needed; and
f) Route surveys and permissions should be obtained if crossing bridges or navigating urban areas.
g) Large element transportation time slots through day/night per local regulations.

7.3.2 *Factory Stockyard and Logistics Coordination*

Precast elements in the factory stockyard should be stored using first in, first out (FIFO) or last in, first out (LIFO) methods, depending on site requirements. Proper stock registers and inventory management software should be used for efficient tracking and organization. Storage size of the yards should be defined by the minimum concrete strength and curing periods.

7.3.3 *Crane Planning*

Collaborate with the installation planning engineers to create a comprehensive crane layout, considering:

a) Types of cranes (tower cranes, mobile cranes);
b) Site constraints (space, access);
c) Ground strata for crane footing;
d) Lifting capacities and feeding locations; and
e) Crane removal and repositioning areas.
f) Double handling constraints due to storage at site or crane reach.

7.4 Installation Sequence

Once the casting sequence is set, assign installation dates to each element based on factors such as:

a) Crane type and operational speed;
b) Reduced crane efficiency where multiple cranes are deployed with overlapping zones
c) Element type and installation cycle time;
d) Connection complexity;
e) Grouting and curing durations;
f) The number of shifts and crane operation hours; and
g) Adjust installation dates and resources as needed based on available machinery and logistics.

7.5 On site work Planning

7.5.1 *Surveying*

The first activity on-site is surveying and line-out. Ensure key points are marked, including:

a) Building corners and faces;
b) Compound wall boundaries;
c) Grid lines and column centres;
d) Footing corners; and
e) Shear wall grid lines.
f) Site constraints such as High-Tension lines or existing canals or water bodies or filled up areas or marsh lands.

7.5.1.1 Drone surveys are recommended for more accurate and automated site measurements, which also help in progress tracking.

7.5.2 *Cast-In Situ Works*

Cast-in-situ (CIS) work is crucial in precast projects. The interface between precast and CIS activities typically occurs during installation and connection phases. Minimizing inter-trade dependencies improves project success in terms of time and cost. This interface also needs careful attention to the Precast elements connection dowels that are placed in CIS that may have higher variation that affects Precast installation. Detailed as-built surveys much be completed well ahead of time to avoid last minute repairs and long delays.

7.6 Digital Tracking and Monitoring Tools

To enhance precision and efficiency, implement Building Information Modelling (BIM) for both production and assembly of precast elements. This technology supports:

a) Real-time drawing access by all engineers, reducing errors; and
b) Seamless use across production, installation, and progress monitoring stages.
c) Required infrastructure such as Wi-Fi network and system access between various agencies should be in place.

8 CONSTRUCTION AND MANUFACTURE OF PRECAST CONCRETE ELEMENTS

8.1 Manufacture of Precast Concrete Elements

8.1.1 A strategically located precast facility, with careful consideration of raw material availability, storage, proper logistics, and access to erection equipment, will help achieve economies of scale

8.1.2 *Manufacture*

The manufacturing of components can take place in a factory for commercial purposes, based on market potential, or in an on-site yard or nearby location for a specific project. For reduction in site pollution and wastage to achieve sustainability in precast construction **F-4** shall be referred.

8.1.2.1 *Factory prefabrication*

Factory prefabrication involves the commercial production of standardized components in a factory setting, typically for long-term manufacturing. It is a capital-intensive process where work is carried out year-round, ideally under a covered shed to minimize the impact of seasonal variations. This type of facility allows for high levels of mechanization, with production organized in a factory-like manner, supported by a consistent team of workers.

8.1.2.2 *Site prefabrication*

Site prefabrication refers to the production of prefabricated components directly at the construction site or nearby. This approach is usually adopted for large-scale projects that span a long duration. It offers significant cost savings, particularly in transportation, and enhances productivity. Although temporary, the site factory should be comparable to a high-capacity permanent facility, with state-of-the-art mechanization and strict quality control. There are two types of site prefabrication as follows:

a) *Semi-mechanized* – In this approach, work is typically performed in an open area using a locally available labour force, with the level of skill required varying based on the complexity of the project. The machinery and equipment used are minimal, and the mould may be mobile or stationary.
b) *Fully-mechanized* – Work is conducted under a covered shed with skilled labour, and the machinery used is similar to that found in factory settings. This type of yard is designed for high-quality, high-production output, ensuring the efficient manufacture of precast components.

8.1.2.3 *Precast factory quality audits*

All precast manufacturing facilities, permanent or temporary, must have a yearly quality audit at minimum with a team of competent inspectors mutually agreed by the authority and the contractor.

8.1.3 The various processes involved in the manufacture of precast elements can be classified as follows

8.1.3.1 *Core process*

The main processes include the following steps:

a) Providing and assembling moulds, positioning the reinforcement cage for reinforced concrete work, and stressing the wires for prestressed elements.
b) Installing concealed service conduits/pipes.
c) Fixing inserts and tubes as necessary (for handling purposes).
d) Pouring concrete into the moulds;
e) Vibrating and finishing the concrete.
f) Curing the concrete.
g) Demoulding the forms and stacking the precast products.

8.1.3.2 *Auxiliary process*

These processes are necessary for the successful completion of the core processes:

a) Mixing and producing fresh concrete (carried out in a mixing station or batching plant);
b) Prefabricating the reinforcement cage (performed in a steel yard or workshop);
c) Manufacturing inserts and other finishing components to be incorporated into the main precast products.
d) Finishing the precast products.
e) Testing the precast products.

8.1.3.3 *Subsidiary process*

These processes support the core production cycle, including:

a) Storing of materials.
b) Transporting cement and aggregates.
c) Transporting green concrete and reinforcement cages.
d) Transporting and stacking precast elements.
e) Repairing and maintaining tools, shackles, and machinery.
f) Repairing and maintaining moulds;
g) Maintaining curing yards;
h) Generating steam, etc.

8.1.4 The manufacturing of precast elements requires systematic planning of all the processes to achieve the following objectives:

a) A cyclic working method to enhance speed and cost-efficiency in production;
b) Mechanization of processes to boost productivity and improve quality;
c) Optimal production levels that meet quality control standards while maintaining the desired construction speed;
d) Improved working conditions for the workforce; and
e) Minimization of weather-related disruptions to the manufacturing schedule.

8.1.5 The various stages of precasting, as outlined in Table 12, are classified based on the equipment required for each stage. This classification facilitates the mechanization and rationalization of work throughout the process. Stages 6 and 7, as shown in Table 12, represent the core processes in the manufacturing of precast concrete elements. For these stages, various technological processes are employed, tailored to the specific concrete product being produced. These methods have been proven to be rational, economical, and time-saving. Figure 40 provides a diagrammatic representation of the different stages involved in the plant process.

8.1.6 The accepted methods of manufacturing precast units can be broadly classified into two categories:

a) The stationary method, where the moulds remain in a fixed position, and the various processes are carried out in a cyclic order at the same location; and
b) The circulation method, where the precast unit moves through different stages of production, with the processes being carried out in an assembly-line fashion

The various accepted pre-casting methods are listed in **Error! Reference source not found.** with details regarding the elements that can be manufactured by these methods.

Table 12 Stages of Precasting of Concrete Products
(*Clause* 8.1.5)

Sl No.	**Precasting Stage No.**	**Name of Process**	**Operations Involved**
(1)	(2)	(3)	(4)
i)	1	Procurement and storage of construction materials	Unloading and transport of cement, coarse and fine aggregates and steel, and storing them in bins, silos or storage sheds
ii)	2	Testing of materials	Testing of all materials including steel
iii)	3	Design of concrete mix	Testing of raw materials, plotting of grading curves and trial of mixes in laboratory
iv)	4	Making of reinforcement cages	Unloading reinforcement bars from wagons or lorries and stacking them in the steel yard, cutting, bending, tying or welding the reinforcements and making in the form of a cage, which can be directly introduced into the mould
v)	5	Applying form release agent and laying of moulds in position	Moulds are cleaned, applied with form release agent, and assembled and placed at the right place
vi)	6	Placing of reinforcement cages, inserts and fixtures	The reinforcement cages are placed in the moulds with spacers, etc, as per data sheet prepared for the specific prefabricate units
vii)	7	Preparation of green concrete	Taking out aggregates and cement from bins, silos, etc, batching and mixing
viii)	8	Transport of green concrete	Transport of green concrete from the mixer to the moulds. In the case of precast method involving direct transfer of concrete from mixer to the mould or a concrete hopper attached to the mould this prefabrication stage is not necessary
ix)	9	Pouring and consolidation of concrete	Concrete is poured and vibrated to a good finish

Sl No.	**Precasting Stage No.**	**Name of Process**	**Operations Involved**
(1)	(2)	(3)	(4)
x)	10	Curing of concrete and demoulding	Either natural curing with water or an accelerated curing using steam and other techniques. In the case of steam curing using trenches or autoclaves, this stage involves transport of moulds with the green concrete into the trench or autoclave and taking them out after the curing and demoulding elements. Cutting of protruding wires also falls in this stage. In certain cases, the moulds have to be partly removed and inserts have to be removed after the initial set. Final demoulding is done after concrete has gained designed strength, enough to resist handling stress, and the components are then allowed to be cured further. All these falls in this operation. The minimum curing duration is per good practice [6-7(3)] except in cases where the design strength of the precast element is achieved earlier. In that case, curing only upto achieving the design strength is sufficient, subjected to appropriate approvals.
xi)	11	Stacking of precast elements	Lifting of precast elements from the mould and transporting to the stacking yard for further transport by trailer or rail is part of this stage
xii)	12	Testing of finished components	Tests are carried out on the components individually and in combination to ensure the adequacy of their strength
xiii)	13	Miscellaneous	a) Generation of steam involving storing of coal or oil necessary for generation of steam and providing insulated steam pipe connection up to the various technological lines b) Repair of machines used in the production

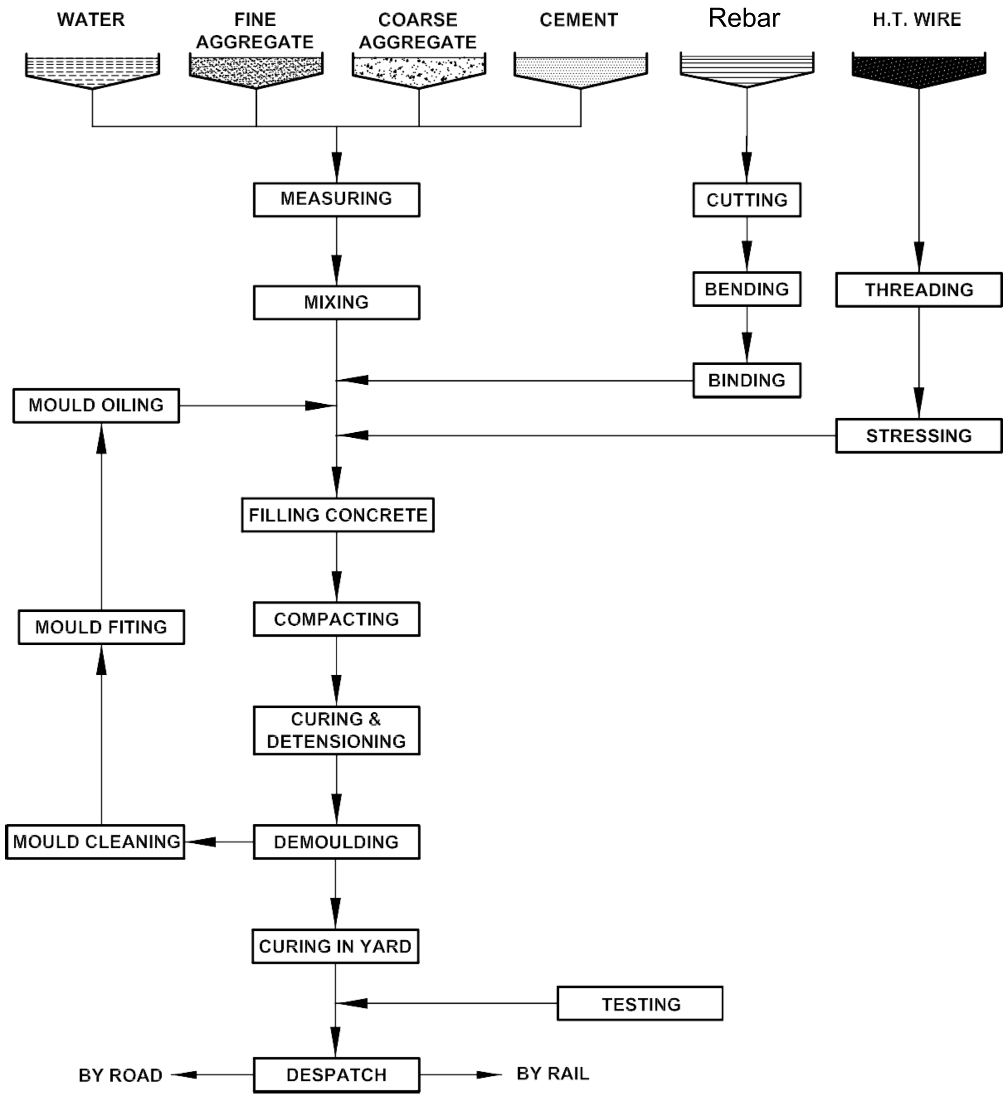


FIG. 40 PLANT PROCESS

Table 13 Precasting Methods
(*Clause* 8.1.6)

Sl No.	Precasting Method	Where used	Recommended Dimensions and Weights	Advantages and Remarks
(1)	(2)	(3)	(4)	(5)
i)	*Individual mould method* — Precasting method using mould which may be easily assembled out of bottom and sides, transportable, if necessary. This may be either in timber or in steel using needle or mould vibrators and capable of taking pre-stressing forces	Ribbed slabs, beams, girders, window panels, box type units and special elements Prestressed railway sleepers, parts of pre- stressed girders, etc.	No limit in size and weight. It depends on the equipment used for demoulding, transporting and placing	Strengthening of the cross-section possible Openings are possible in two planes
ii)	*Battery mould method* — The shuttering panels may be adjusted into the form of a battery at the required distances equal to the thickness of the concrete member	Interior wall panels, shell elements, reinforced concrete battens, rafters, purlins, roof and floor slabs	Length: 9 m Height: 3 m Mass: 5 t	Especially suitable for mass production of wall panels where shuttering cost largely reduced. Vapor or Steam curing may be adopted by taking the steam pipes through the shuttering panels
iii)	*Stack method*	Floor and roof slab panels	Length: Any desired length Breadth: 1 to 4 m Mass: 5 t	For casting identical reinforced or pre-stressed panels one over the other with separating media interposed in between
iv)	*Tilting mould method* — This method is capable of being skipped vertically using hydraulic jacks	Exterior wall panels where special finishes are required on one face or for sandwich panel	Length : 6 m Breadth : 4 m Mass : 5 t	Suitable for manufacturing the external wall panels
v)	*Long line prestressing bed method*	Double tees, ribbed slabs, purlins, piles and beams	Length : Any Desired length Breadth : 2 m Height : 2 m Mass : Up to 10 t	Ideally suited for pretension members
vi)	*Extrusion method* —Long concrete mould with constant cross-section where concreting and vibration are done automatically just as in hollow cored slab casting	Roof slabs, foam concrete wall panels and beams cross-section	Length : Any Desired length Breadth : Less than 2 m Height : Less than 3 m	May be used with advantage in the case of un-reinforced blocks, foam concrete panels

8.1.7 *Preparation and Storage of Materials*

Proper storage of materials is crucial in the precast industry, as errors in planning this aspect can significantly impact production economics. In a precast factory, where quality is paramount, the proper storage and preservation of building materials—especially cement, coarse aggregates, and fine aggregates—are essential. Materials should be stored in accordance with accepted standard [6-7(34)]. Additionally, precast elements should follow a ‘first-in, first-out’ (FIFO) system to minimize or avoid issues related to shrinkage, creep, and other material-related concerns.

8.2 Moulds

8.2.1 Moulds used for the manufacture of precast elements may be made from steel, timber, concrete, plastic, or a combination of these materials. When designing moulds for various elements, special attention should be given to facilitating easy demoulding and the assembly of parts. Additionally, the rigidity, strength, and watertightness of the mould are critical, especially considering the forces involved during the pouring of green concrete and the vibrating process. The deflection of any supporting member of the mould shall not exceed L/350 or 3 mm, whichever is less, where L represents the span of the member in millimetres).

8.2.2 Tolerances

The moulds shall be designed to accommodate the tolerances as per the casting tolerances given in Table 14.

Table 14 Casting Tolerances for Precast Components
(*Clause* 8.2.2)

Sl No.	Product Tolerances	Product (see Key No.)
(1)	(2)	(3)
i)	*Length*:	
	a) ± 5 mm	Channel unit (1), Step unit (10), Modular unit (12), Stadium riser (15) Cladding panel/facade (16) H-Frame (17)
	b) ± 10 mm	Column (9), Beam and spandrel (11),
	c) ± 10 mm	Ribbed slab unit/Hollow slab (2), Waffle unit (3), Large panel (4), Prefabricated brick (6), Precast planks (7), Ribbed/plain wall panel (8),

Sl No.	**Product Tolerances**	**Product (see Key No.)**
(1)	(2)	(3)
	d) 1) ± 2 mm for length below and up to 500 mm 2) ± 5 mm for length over 500 mm	Cellular floor/roof slabs (5)
	± 15 mm	Single Tee (13), Double Tee (14) Foundation units (18) Drain (19)
ii)	*Thickness/cross sectional dimensions*:	
	a) ± 3 mm	Channel unit (1)
	b) ± 3 mm or 0.1 percent, whichever is greater	Ribbed slab unit/ hollow slab (2), Ribbed/Plain wall panel (8)
	c) 1) ± 3 mm up to 300 mm thick 2) ± 5 mm greater than 300 mm thick	Large panel (4), Cellular floor/roof slabs (5), Precast planks (7), Step unit (10), Modular unit (12), Stadium riser (15),
	d) ± 5 mm	Waffle unit (3), Prefabricated brick (6), Column (9), Beam and spandrel (11), Cladding panel/facade (16) H-Frame (17) Foundation units (18) Drain (19)
	e) + 5 mm, - 3 mm	Single Tee (13), Double Tee (14)
iii)	Straightness/Bow:	
	a) 1/360 of length, maximum of ± 10 mm	Ribbed slab unit/ hollow slab (2), Large panel (4), Cellular floor/roof slabs (5), Precast planks (7), Ribbed/plain wall panel (8), Step unit (10), Stadium riser (15) Cladding panel/facade (16) Foundation units (18)
	b) ± 3 mm	Channel unit (1), Cellular floor/roof slabs (5)
iv)	Squareness – When considering the squareness of the corner, the longer of two adjacent sides being checked shall be taken as the base line, and the following tolerances shall apply:	Ribbed slab unit/Hollow slab (2), Waffle unit (3), Large panel (4), Cellular floor/roof slabs (5), Prefabricated brick (6),

Sl No.	Product Tolerances	Product (see Key No.)
(1)	(2)	(3)
		Precast planks (7), Ribbed/plain wall panel (8), Column (9), Step unit (10), Beam and spandrel (11), Modular unit (12), Single Tee (13), Double Tee (14) Stadium riser (15) Cladding panel/facade (16) H-Frame (17) Foundation units (18) Drain (19)
	skew across width of an end	
	± 3 mm per 300 mm length, with maximum of ± 5 mm	Stadium riser (15),
	± 3 mm per 300 mm length, with maximum of ± 10 mm	Column (9), Precast planks (7),
	± 3 mm per 300 mm length, with maximum of ± 15 mm	Channel unit (1), Ribbed slab unit/ hollow slab (2), Large panel (4), Cellular floor/roof slabs (5), Ribbed/plain wall panel (8), Step unit (10), Beam and spandrel (11),
	Skew across thickness or depth or height of an end	
	± 3 mm	Modular unit (12), Cladding panel/facade (16)
	± 3 mm per 300 mm length	Large panel (4), Precast planks (7), Ribbed/plain wall panel (8), Cladding panel/facade (16)
	Depth ≤ 600 mm, ± 5 mm Depth ≥ 600 mm ± 1.5 mm for 300 mm length with maximum of ± 15 mm	Single Tee (13), Double Tee (14)
v)	Twist – Any corner shall not be more than the tolerance given below from the plane containing the other three corners:	Ribbed slab unit/ hollow slab (2), Ribbed/Plain wall panel (8)

Sl No. (1)	Product Tolerances (2)	Product (see Key No.) (3)
	a) 1) Up to 600 mm in width and 5 mm up to 6 m in length 2) Over 600 mm in width and for any length 10 mm	
	± 1/1 500 of dimension or ± 5 mm. whichever is less	Large panel (4)
	± 3 mm	Channel unit (1)
	± 1 mm	Precast planks (7)
vi)	Flatness – The maximum deviation from 1.5 m straight edge placed in any position on a nominal plane surface shall not exceed:	Ribbed slab unit/ hollow slab (2), Ribbed/Plain wall panel (8)
	± 5 mm	
	± 3 mm	Large panel (4)
	± 2 mm	Channel unit (1), Precast planks (7)
	± 5 mm or maximum of 0.1 percent length	Cellular floor/roof slabs (5)
vii)	Warping: Deviation from plane in which the corners of the panel do not fall within the same plane	
	± 1.5 mm per 300 mm length	Ribbed slab unit/Hollow slab (2), Large panel (4), Cellular floor/roof slabs (5), Precast planks (7), Ribbed/plain wall panel (8), Cladding panel/facade (16) Foundation units (18)
	± 5 mm	Step unit (10), Stadium riser (15)

1 Channel unit.
2 Ribbed slab unit/hollow slab.
3 Waffle unit.
4 Large panel prefabrication.
5 Cellular floor/roof slabs.
6 Prefabricated brick panel.
7 Precast planks.
8 Ribbed/plain wall panel.

Sl No.	Product Tolerances	Product (see Key No.)
(1)	(2)	(3)
9	Column	
10	Step unit	
11	Beam and spandrel (11),	
12	Modular unit (12),	
13	Single Tee (13),	
14	Double Tee (14)	
15	Stadium riser (15)	
16	Cladding panel/facade	
17	H-Frame	
18	Foundation units	
19	Drain	

8.2.3 *Mould Wall Slopes*

To facilitate the easy removal of precast elements from the mould, particularly when the mould has fixed sides and the elements need to be lifted out, the side slopes should ideally be 1 in 6 but shall not be less than 1 in 12. For slopes less than 1 in 6, the mould should have provisions of appropriate hydraulic jacks at the base of the mould to assist demoulding. A gentle slope helps prevent the elements from becoming stuck in the mould during demoulding.

8.3 Accelerated Curing

In precasting factories, using accelerated or artificial curing methods is economical, as it allows elements to be demoulded much earlier, enabling the early re-use of moulds. Any of the following methods may be adopted:

8.3.1 *Steam Curing*

8.3.1.1 The steam curing of concrete products shall take place under tarpaulin in tents, under hoods, under chambers, in tunnels or in special autoclaves. The steam shall have a uniform flow throughout the length of the member. The precast elements shall be so stacked with sufficient clearance between each other and the bounding enclosure, to allow proper circulation of steam.

8.3.1.2 Before the concrete products are subjected to any accelerated method of curing, the cement to be used shall be tested for soundness, setting time and suitability for steam curing.

8.3.1.3 In the case of elements manufactured by accelerated curing methods, concrete admixtures to reduce the water content may be allowed to be used. The normal aeration agents used to increase the workability of concrete should not be allowed to be used. Use of calcium chloride-based admixtures should not be used for reinforced concrete elements so as to meet the chloride limits prescribed in good practice [6-7(3)].

8.3.1.4 The inside face of the steam curing chamber, tunnel or hood shall have a damp-proof layer to maintain the humidity of steam. Moreover, a proper slope shall be given to the floor and the roof to allow the condensed water to be easily drained away. First, when steam is let into the curing chambers, the air inside shall be allowed to go out through openings provided in the hoods or side walls which shall be closed soon after moist steam is seen jetting out.

8.3.1.5 It is preferable to let in steam from the top of the chamber through perforated pipelines to allow uniform entry of steam throughout the chamber.

8.3.1.6 The fresh concrete in the moulds should be allowed to get the initial set before allowing the concrete to come into contact with steam. The regular heating up of fresh concrete products from about 20°C to 35°C should start only after a waiting period ranging from 2 h to 5 h depending on the setting time of cement used. It may be further noted that steam can be let in earlier than this waiting period provided the temperature of the concrete product does not rise beyond 35°C within this waiting period.

8.3.1.7 The second stage in steam curing process is to heat up the concrete elements, moulds and the surroundings in the chamber:

a) In the low-pressure steam curing, the airspace around the member is heated up to a temperature of 75°C to 80°C at a gradual rate, usually not faster than 30°C /hr (this process takes around 1 h to 1 h 30 min depending upon outside temperature); and
b) In the case of curing under high pressure steam in autoclaves, the temperature and pressure are gradually built up during a period of about 4 h.

8.3.1.8 The third stage of steam curing is to maintain the uniform temperature and pressure for a duration depending upon thickness of the section. This may vary from 3 h to 5½ h in the case of low-pressure steam curing and 4 h to 7 h in the case of high-pressure steam curing.

8.3.1.9 The fourth stage of steam curing is the gradual cooling down of concrete products and surroundings in the chamber and normalization of the pressure to bring it at par with outside air. The maximum cooling rate, which is dependent on the thickness of the member, should normally not exceed 30°C/h.

8.3.1.10 In all these cases, the difference between the temperature of the concrete product and the outside temperature should not be more than 60°C for concrete up to M30 and 75°C for concretes greater than M45. In the case of light weight concrete, the difference in temperature should not be more than 60°C for concretes less than M25. For concretes greater than M50, the temperature differences can go up to 75°C.

8.3.2 *Vapour Curing* – Vapour curing of concrete is a method used to promote proper hydration of the concrete mix, which is essential for the development of its strength and durability. Unlike traditional curing methods (such as water spraying or covering with wet burlap), vapour curing uses the application of moisture in the form of vapour or steam to maintain a high relative humidity around the concrete during the curing process. The same system can also be used as steam curing with similar requirements as noted in **8.3.1**. The temperature range in this case varies from manufacturer to manufacturer.

8.3.3 *Steam injection during mixing of concrete* — In this method, low pressure saturated steam is injected into the mixer while the aggregates are being mixed. This enables the heating up of concrete to approximately 60°C. Such concrete after being placed in the moulds attains high early strength.

8.3.4 *Heated air method* — In this method, the concrete elements are kept in contact with hot air with a relative humidity not less than 80 percent. This method is especially useful for light weight concrete products using porous coarse aggregates.

8.3.5 *Hot water method* — In this method, the concrete elements are kept in a bath of hot water around 50°C to 80°C. The general principles of this type of curing are not very different from steam curing.

8.3.6 *CO_2 curing – An emerging curing technique* — CO_2 curing is an innovative process that utilizes carbon dioxide (CO_2) to accelerate the curing of concrete and enhance its strength. During mixing, CO_2 is injected into the concrete, promoting faster hydration. This technique is particularly effective in accelerating the fabrication of precast concrete elements, improving both the efficiency and quality of the final product.

8.3.7 After the accelerated hardening of the above products by any of the above accepted methods, the elements shall be cured further by normal curing methods to attain full final strength.

8.3.8 Accelerated hardening may also be achieved by the following techniques:

a) *Construction chemicals* — Suitable construction chemicals may be used.
b) *Consolidation by spinning* — Such a method is generally used in the centrifugal moulding of pipes and such units. The spinning motion removes excess water, effects consolidation and permits earlier demoulding.
c) *Pressed concrete* — This method is suitable for fabrication of small or large products at high speed of production. A 100 to 200 t press compresses the wet concrete in rigid moulds and expels water. Early handling and a dense wear resistant concrete is obtained.
d) *Vacuum treatment* — This method removes the surplus air and water from the newly placed concrete as in slabs and similar elements. A suction upto about 70 percent of an atmosphere is applied for 20 to 30 min/cm thickness of the units.
e) *Consolidation by shock* — This method is suitable for small concrete units dropped repeatedly from a height in strong moulds. The number of shocks required to remove excess water and air may vary from 6 to 20 and the height of lift may be up to as much as half the depth of the mould.

8.3.8.1 After the accelerated curing of the above products by any of the above accepted methods, the elements shall be cured further by normal curing methods to attain full final strength.

8.3.9 Stacking during transport and storage

Every precaution shall be taken against overstress or damage, by the provision of suitable packing at agreed points of support. In general, the final condition of the elements in the structure should be studied to finalize on the staking support. Even the number of supports is preferred over the odd number of supports. Particular attention is directed to the inherent dangers of breakage and damage caused by supporting other than at two positions, and by the careless placing of packing (for example, not vertically one above the other). Ribs, corners and intricate projections from solid section should be adequately protected. Packing pieces shall not stain, disfigure or otherwise permanently cause mark on units or members. Stacking shall be arranged, or the precast units should be protected, to prevent the accumulation of trapped water or rubbish and, if necessary, to reduce the risk of efflorescence.

The following points shall be kept in view during stacking:

a) Care should be taken to ensure that the flat elements are stacked as per their final position at the structure. For identification, top surfaces should be clearly marked.
b) Stacking should be done on hard and suitable ground to avoid any sinking of support when elements are stacked.
c) In case of horizontal stacking, packing materials shall be at specified locations and shall be exactly one over the other to avoid cantilever stress in panels.
d) Components should be packed in a uniform way to avoid any undue projection of elements in the stack which normally is a source of accident.
e) In general, vertical stacking should be limited to 6-10 components. Where the ground is only compacted, the maximum ground load at support should be restricted to 15 t/m^2 and the stacking should be restricted to 6 panels. Where PCC layer is poured, the maximum ground load at support should be restricted to 30 t/m^2 and the stacking should be restricted to 10 panels. In both cases, the ground should be levelled, and the support should be continuous along the width of the panels.
f) All wall panels shall be stacked, preferably symmetrically on both sides, against steel A-frames. The slope of the sides of the A-frame shall be between 75° and 80° to the horizontal and the bottom of the frame shall be provided with concrete footings to resist component of self- weight and horizontal wind pressure on the wall panel. A similar type of A-frame should be used for transporting wall panels.

8.4 Handling Arrangements

8.4.1 Lifting and handling positions shall be clearly defined particularly where these sections are critical. Where necessary special facilities, such as bolt holes or projecting loops, shall be provided in the units and full instructions supplied for handling. For bolts/hooks, bond strength shall be the criteria for embedded bolts and bearing strength for through bolts. For bond strength, pull out test of concrete shall be carried out. *See* **8.8** for additional design considerations.

8.4.2 For precast pre-stressed concrete members, the residual pre-stress at the age of operation of handling and erection shall be considered in conjunction with any stresses caused by the handling or erection of member. The compressive stress thus computed shall not exceed 50 percent of the cube strength of the concrete at the time of handling and erection. Tensile stresses up to a limit of 50 percent above those specified in good practice [6-7(3)] shall be permissible.

8.5 Identification and Marking

All precast units shall bear an indelible identification, location and orientation marks as and where necessary. The date of manufacture shall also be marked on the units.

The identification markings on the drawings shall be the same as that indicated in the manufacturer's literature and shall be shown in a tabular format on the setting schedule together with the length, type, size of the unit, and the sizes and arrangement of all reinforcement. Implementation of QR code stickers pasted on precast elements with above mentioned details are highly recommended.

8.6 Transport

Transport of precast elements inside the factory and to the site of erection is of considerable importance not only from the point of view of economics but also from the point of view of design and efficient management. Transport of precast elements must be carried out with extreme care to avoid any impact and distress in elements and handled as far as possible in the same orientation as it is to be placed in the final position. *See* **8.8** for additional design considerations.

8.6.1 *Transport Inside the Factory*

Transport of precast elements moulded inside the factory depends on the method of production selected for the manufacture as given in Table 13.

8.6.2 *Transport from Stacking Yard Inside the Factory to the Site of Erection*

Transport of precast concrete elements from the factory to the site of erection should be planned in such a way to be in conformity with the traffic rules and regulations as stipulated by the Authorities. The size of the elements is often restricted by the availability of suitable transport equipment, such as tractor-*cum*- trailers, to suit the load and dimensions of the member in addition to the opening dimensions under the bridge and load carrying capacity while transporting the elements over the bridge.

8.6.2.1 While transporting elements in various systems, that is, wagons, trailers, trucks, etc, care should be taken to avoid excessive cantilever actions and desired support are maintained. Transportation of prefabricated elements should be carried out with care. Sufficient care should be taken to also protect the steel inserts and reinforced bars of the precast elements during transportation. Precast elements should be secured with safety ties to ensure that vibrations to the elements in transit are minimum. Special care should be taken at location of sharp bends and on uneven or slushy roads to avoid undesirable stresses in elements.

8.6.2.2 Before loading the elements, care should be taken to ensure that the base packing for supporting the elements is located at specified positions only. Subsequent packing shall be kept strictly one over the other.

8.7 Erection

Tower cranes or other mobile cranes have varying lifting capacities at different radii, with the maximum weight at a radius closer to the centre and the minimum weight at a radius farther from the centre. To minimize the number of precast elements, the selected crane should be capable of handling the heaviest precast elements at its maximum radius. The floor plan should indicate the weight of panels at different crane radii, ensuring they align with the crane's lifting capacity at each radius.

In the erection of precast elements, all the following items of work are meant to be included:

a) Slinging of the precast element;
b) Tying up of erection ropes connecting to the erection hooks;
c) Cleaning of the elements and the site of erection;
d) Cleaning of the steel inserts before incorporation in the joints, lifting of the elements, setting them down into the correct envisaged position;
e) Adjustment to get the stipulated level, line and plumb by means of levelling bolts and adjustable props;
f) Welding of cleats;
g) Changing of the erection tackles;
h) Putting up and removing the necessary scaffolding or supports;
i) Welding of the inserts, laying of reinforcements in joints and grouting the joints; and
j) Finishing the joints to bring the whole work to be like finished product.

See **8.8** for additional design considerations.

8.7.1 Since the erection work in various construction jobs using prefabricated concrete elements differs from place to place depending on the site conditions, safety precautions in the work are of utmost importance. Hence, only those skilled foremen, trained workers and fitters who have been properly instructed about the safety precautions to be taken should be employed on the job. For additional information, *see* relevant Indian Standards for safety during construction.

8.7.2 Transport of people, workers or visitors, by using cranes shall be strictly prohibited on an erection site.

8.7.3 For travelling cranes

a) The travel tracks shall be perfectly levelled both longitudinally and transversally.
b) The gauge shall be constant and the rail tracks perfectly straight and with the same shape along the entire path;
c) The rail tracks shall be placed on a solid base;
d) Travelling stop buffers shall be placed at the ends of the rail tracks;
e) For rail shape tolerances, the OEM's installation manual shall be referred.

f) The track of the crane should be checked daily to see that all fish plates and bolts connecting them to the sleepers are in place and in good condition.

8.7.4 The operation of all equipment used for handling and erection shall follow the operations manual provided by the manufacturer. All safety precautions shall be taken in the operations of handling and erection.

8.7.5 *Erection Tolerances*

Erection tolerance shall be as per Table 15.

Table 15 Erection Tolerance for Precast Components
(*Clause* 8.7.5)

Sl No. (1)	**Product** (2)	**Tolerances** mm (3)
i)	Level differences between support lines of floor or wall panels	± 5
ii)	Plumb lines of wall panels	± 5
iii)	Bearing for precast floor panels	± 5
iv)	Joint dimensions	± 5
v)	Maximum accumulated deviation	1/1250 of height or length or ± 20
vi)	Variation in plan location (any column or beam, any location).	± 10 for column ± 15 for beams
vii)	Variation in plan parallel to specified building lines	+2mm per meter for any beam less than 6 m long or adjacent to columns paced less than 6 m apart 15 mm maximum for adjacent columns spaced more than 6 m

8.8 Design Considerations

Based on the design intent, production environment and aesthetic requirements of the prefabricated panels, the resultant stresses should be controlled to minimize cracking in precast and/or prestressed panels. Precast (non-prestressed) components are generally designed as ‘cracked’ unless cracking is an aesthetic concern. However, demoulding of precast elements shall not be allowed until the concrete achieves a strength of at least 1.25 times the (extreme fibre) stress which the concrete may be subjected at the time of demoulding. The same shall be applicable while transporting and erection. Refer Table 7 for load multiplier to ascertain handling stress. The strength referred to shall be that of concrete using the same cement and aggregates and admixture, if any, with the same proportions and cured under conditions of temperature and moisture similar to those existing on the work.

8.8.1 Structural design requirements of minimum spacing, skin reinforcement and crack width criteria as specified in good practice [6-7(3)] are applicable.

8.8.2 Lifting hooks should be located such that while lifting the panel, minimum bending moments are produced.

8.8.3 Static load multipliers should be used to account for impact, and demoulding forces as per Table 7.

8.8.4 The load multipliers are only needed for the flexural design and are not applicable for the lifting devices. Lifting hooks shall be designed as per **5.14.6**.

8.8.4.1 For wall panels cast vertically on tilting moulds, battery moulds, and other vertically cast elements, the required concrete strength is not always dictated by flexural stresses. Instead, the minimum concrete strength during the initial lift may be governed by the capacity requirements of the lifting inserts. The capacity of the lifting inserts may be lower than their rated value due to factors such as inadequate embedment depth, insufficient edge distances, or low concrete strength at the time of lifting. Therefore, higher concrete strengths than those recommended in **Error! Reference source not found.** may be necessary to fully develop the capacity of certain lifting inserts and ensure the safe handling of the panels.

8.8.4.2 For prestressed elements, special care must be taken to ensure that lifting devices are anchored in compression zones, unless otherwise specified by the design.

8.8.4.3 Initial lifting should be done cautiously and gradually to overcome suction and friction, avoiding the application of sudden impact forces.

8.9 Equipment

8.9.1 The Strategic equipment used in the precast concrete industry/ construction may be classified into the following categories:

a) Production equipment: Batching plant, Concrete shuttle conveyors concrete vibrators, Circulation tables, EOT, Gantry, Shear lines, stirrup making machines, Weld mesh machines, Robots;
b) Erection equipment, such as Tower cranes, Mobile cranes, derricks, hoists, chain pulley blocks, etc;
c) Transport machinery, such as tractor-*cum*-trailers, dumpers, lorries, locomotives, and rarely even helicopters;
d) Workshop machinery for making and repairing steel and timber moulds;
e) Minor tools and tackles, such as lifting equipment, Electric Vehicle-Dumpers, concrete buckets, etc; and
f) Steam generation plant for accelerated curing.

8.9.1.1 Each of the above groups may further be classified into various categories of machines and further to various other types depending on the source of power and capacity. For use of renewable energy sources to achieve sustainability in precast construction **F-3** shall be referred.

8.9.1.2 Age of mechanical equipment deployed in the start of the factory/project shall be limited based on the purpose listed below:

a) Concrete production, transportation and placing equipment age shall not be more than 7 years from the date of manufacture.
b) Age of precast installation equipment such as Tower crane, crawler crane etc. shall be limited to 10 years from the date of manufacture.
c) Lifting tackles and tools used for Precast element handling shall be certified by competent authority.
d) In the case of multiple cranes operating in the same location, overlapping operating radii shall be equipped with anti-collision devices to prevent accidents.

8.9.2 *Mechanization of the Construction and Erection Processes*

The processes can be mechanized/automated, similar to other industries, to achieve the benefits of mass production of standardized components. This approach will enhance productivity, lower production costs over time, and ensure consistent product quality. For equipment, see relevant Indian Standards.

8.10 Systems for Mixed and Composite Construction

The system of mixed and composite construction depends on the extent of the use of prefabricated components, their materials, sizes and the technique adopted for their manufacture and use in building.

8.10.1 *Combinations of System Components for Mixed and Composite Construction*

The following combinations may be used in mixed and composite construction:

a) Structural steel work and timber roofs on precast frames;
b) Precast half slab, solid slabs, hollow core slabs (floors) onto steel and concrete beams, and masonry walls;
c) Profiled metal decking on precast beams;
d) Cast in situ slab on precast wall;
e) Precast slab on cast in situ wall/ 3D printed wall;
f) Precast frames onto cast in-situ foundations, retaining walls, etc;
g) Precast frames stabilized by masonry walls, steel bracing, etc;
h) Precast cladding in steel or cast in-situ frames and vice-versa;
j) Glass curtain walling, stone cladding or metal sheeting onto precast concrete frames, etc; and
k) Reinforced concrete and structural steel as composite columns and beams.

8.10.2 Precast concrete may be combined with cast in-situ concrete, often termed hybrid construction. Cast in-situ is mostly used to form homogenous connections between precast elements and provide a structural topping for horizontal diaphragm action. In other cases, it is used to form the foundations and sub-structure to the building.

8.10.3 Structural steel work is largely used in long span prestressed concrete floors (hollow core) supported on rolled and prefabricated steel beams and also as steel roof trusses supported on concrete columns.

8.10.4 Timber may be used as long span glue-laminated beams and rafters, with precast concrete. Precast floors may be used in timber frame construction. Similarly, timber frames with precast elements shall be used as a building system.

8.10.5 Brick and block masonry may be combined with precast concrete structures and floors. The most common combination is to use prestressed floors on load bearing walls.

NOTE — Any prefabricated floor system covered under other Indian Standards, for example, reinforced concrete plank system and speed floor system may be combined with load bearing masonry walls/insulating concrete form (ICF) walls/ precast large reinforced concrete wall panels/precast or cast in-situ reinforced concrete column-beam frames provided overall structural design safety, stability and integrity for composite structure is ensured in accordance with this standard and other safety standards, such as good practice [6-7(35)] including fire safety and safety against progressive collapse as per provisions of respective Indian Standards, such as good practice [6-7(36)].

8.10.6 Design considerations

The mixed and composite structures shall be analysed appropriately and the joints in them designed to take the forces of an equivalent discrete system. Resistance to horizontal loading shall be provided by placing beams, walls and/or bracings in two directions at right angles or otherwise. The individual components shall be designed, taking into consideration appropriate end conditions and loads at various stages of construction. The components of the structure shall be designed for loads in accordance with good practice [6-7(21)] and [6-7(35)]. In addition, members shall be designed for handling, erection and impact loads that may be expected during handling and erection.

For mixed and composite construction, the following shall be considered:

a) Positions of stability cores, walls, bracing, etc – In high rise buildings, the most popular method is a central core constructed several storeys ahead of the framework. The core could be built using either precast concrete panels, or cast in-situ walls, or steel cross bracing or precast concrete diagonal bracing.
b) Maturity of connections – Cast in-situ grouted joints need temporary propping until desired design strength is achieved unless combined mechanical connections are also used. The overall construction sequence should be planned ahead of time carefully as per the design requirements. The design of temporary bracing system using key components should be looked at critically.
c) Availability and/or positioning of equipment to transport and erect components – The size and weight of the various components shall be organized to make optimum use of crane capacity, for example, the lightest units farthest from the operating zone.
d) Erection safety and speed of construction, with attention to cast in-situ concreting sequences –This is particularly important where fixing gangs are unaccustomed to working with different materials.

e) Tolerances for construction – This is particularly important where different manufacturers are producing components in different materials.

Other design considerations and safety requirements against progressive collapse shall be in accordance with this code.

8.11 Prefabricated Structural Units

For the design and construction of composite structures made up of prefabricated structural units and cast *in-situ* concrete, reference may be made to good practice [6-7(37)].

For design and construction of precast reinforced and prestressed concrete triangulated trusses, reference may be made to good practice [6-7(38)].

For design and construction of floors and roofs using various precast units, reference may be made to good practice [6-7(39)].

For construction with large panel prefabricates, reference may be made to good practice [6-7(40)].

For construction of floors and roofs with joists and filler blocks, reference may be made to good practice [6-7(41)].

9 QUALITY ASSURANCE AND QUALITY CONTROL

The provisions for quality assurance as per good practice [6-7(3)] shall apply. A documented quality assurance program covering various stages from precast unit/element production to erection shall be implemented and maintained. Common defects and remedies in precast concrete elements are presented in Annex E. Annex F shall be referred for transparency, certification and ethical practices to achieve sustainability in precast construction. Additionally, the following flow chart shall be considered.

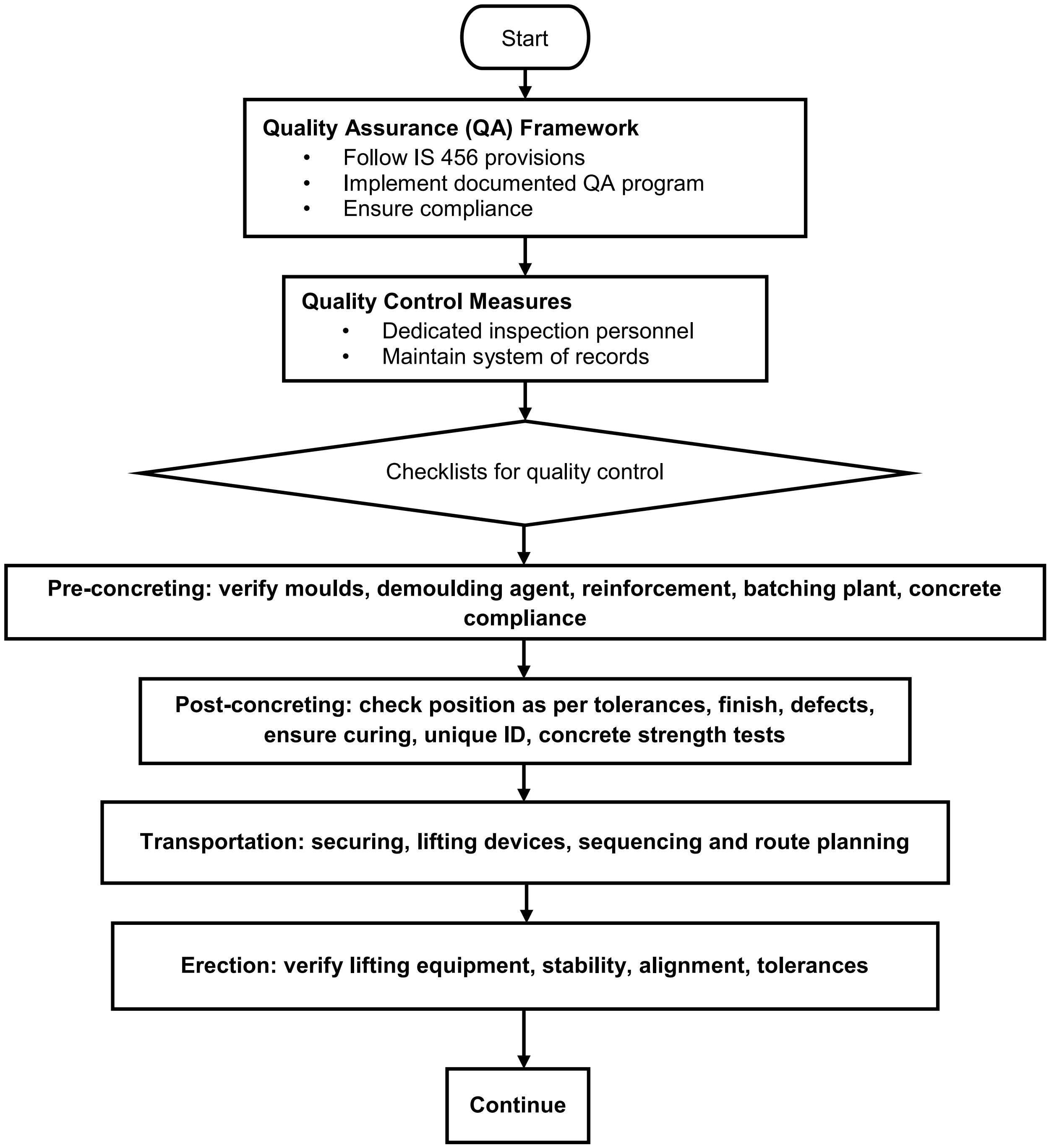


FIG. 41 FLOWCHART FOR QUALITY ASSURANCE AND CONTROL (CONTD.)

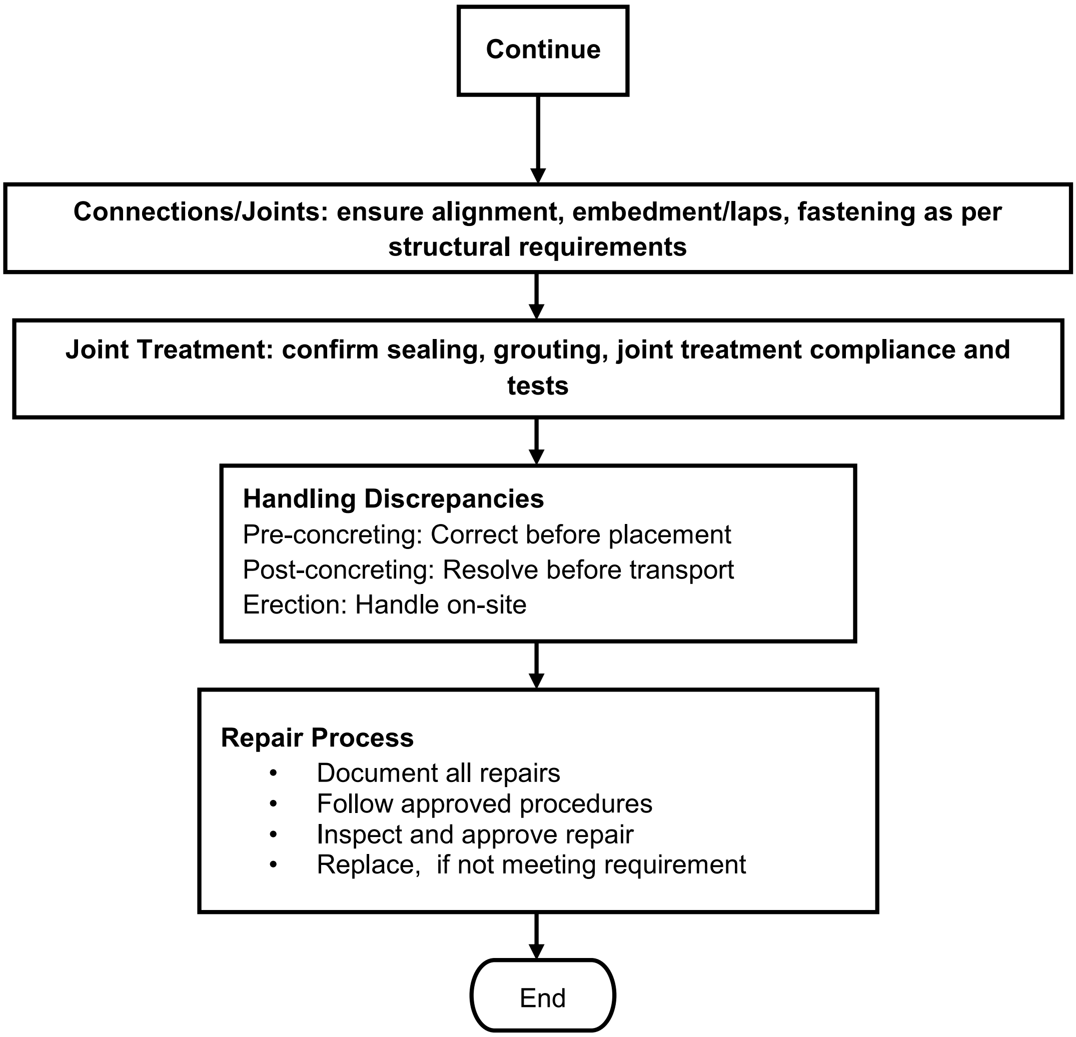


FIG. 41 FLOWCHART FOR QUALITY ASSURANCE AND CONTROL

10 TESTING

10.1 Sampling procedures

10.1.1 *Lot*

10.1.1.1 All the precast units of same size, manufactured from same material under similar conditions of production shall be grouped together to constitute a lot.

10.1.1.2 The number of units to be selected from each lot for dimensional requirements shall depend upon the size of the lot and shall be in accordance with Col 3 and Col 4 of Table 16.

10.1.1.3 The units shall be selected from the lot at random. In order to ensure the randomness of the selection, reference may be made to accepted standard [6-7(42)].

Table 16 Sample Size and Rejection Number
(*Clause* 10.1.1)

Sl No.	Lot Size	First Sample Size	Second Sample Size	First Rejection Number	Second Rejection Number
(1)	(2)	(3)	(4)	(5)	(6)
i)	Up to 100	5	5	2	2
ii)	101 to 300	8	8	2	2
iii)	301 to 500	13	13	2	2
iv)	501 and above	20	20	3	4

10.1.2 *Number of Tests and Criteria for Conformity*

10.1.2.1 All the units selected at random in accordance with **Error! Reference source not found.** shall be subjected to testing of dimensional tolerance requirements. A unit failing to satisfy any of the dimensional requirements shall be termed defective. The following shall be considered:

a) If no defect is found in the sample, the lot shall be considered as conforming or shall be rejected, if the number of defectives is greater than or equal to the first rejection number.

b) If the number of defectives is less than the first rejection number, the second lot shall be subjected to testing for dimensional tolerance requirements.

c) If the combined number of defectives is less than the second rejection number, the lot shall be considered as conforming to dimensional tolerance requirements; otherwise not.

10.1.2.2 The lot which has been found satisfactory with respect to dimensional tolerance requirements shall then be considered for load testing as per **10.4**. One unit out of every 300 units or part thereof shall be selected for testing. The lot shall be considered as conforming to the strength requirement, if all units meet the requirement; otherwise not.

10.2 Testing on Individual Precast Units

10.2.1 The component may be load tested individually or along with the structural topping. If individual element is tested, then the loads to be placed should be prorated such that element experiences similar demand over capacity levels when loaded. In either case, the element should be loaded for 24 h at its full span with a total load of 1.25 times the sum of dead (including its self-weight, SIDL, etc.) and imposed loads used in the design. At the end of this time, it should not show obvious signs of deterioration or excessive deflection. For large span elements, larger than 10 m span, with design stresses near cracking under the ultimate loads, it is not uncommon to see hairline cracks during the load test at maximum loads in sustained conditions. Except for the design criteria of uncracked elements, if applicable, if the test elements in such cases perform at a satisfactory level with recovery as noted in **10.2.2** and **10.2.3** as applicable, the test should be considered passed. If such cracks are substantial, the test should be further evaluated by the engineer of record for acceptance.

10.2.2 The recovery of maximum deflection observed during testing after 24 h should not be less than 75 percent.

10.2.3 If prestressed, it should not show any visible cracks up to the working load, and the recovery of maximum deflection observed during testing after 3 h should not be less than 85 percent.

10.3 Testing of connecting devices and inserts

10.3.1 Grouted coupler or mechanical coupler shall be tested according to accepted standard [6-7(10)]. Where the grouted couplers are used for connections of Lateral Load Resisting System (LLRS) transferring seismic and wind lateral loads, the grouted couplers should also be tested for the reverse cyclic load as per specialist literature and publication in an NABL accredited laboratory or academic institutions under the supervision of appropriate authority.

NOTE: Specialist literature/publication may include International Code Council, ICC ES AC 133, etc.

10.3.2 For any new connection assemblies such as, but not limited to, column shoe or shear connectors, that are used in connection of LLRS as noted in **10.3.1**, shall be tested for monotonic as well as reverse cyclic load test as per specialist literature and publication in an NABL accredited laboratory or academic institutions under the supervision of appropriate authority. The failure should only occur in the reinforcement with evidence of ductility without any damage or deterioration in the brittle components of the connection assembly.

NOTE – Specialist literature/publication may include International Code Council, ICC ES AC 133, etc.

10.3.3 Lifting inserts and devices shall be tested for pull-out and should not show any damage till design load (factor of safety times the working load). Factor of safety shall be according to **5.14**.

10.4 Load Testing of Structure or Part of Structure

10.4.1 Load testing on a part or whole structure should be carried out, if required by specification or to ensure adequacy of strength or serviceability.

10.4.2 The structure should be loaded for 24 h with the full dead load and an imposed load equal to 1.25 times the specified imposed load used in design. The imposed load shall be removed, and the deflection shall be monitored. During the test, vertical struts should be placed appropriately to ensure safety.

NOTE — Dead load includes the self-weight of structural members plus weight of finishes and walls or partitions, if any, as considered in the design.

10.4.3 The recovery of maximum deflection shall be at least 75 percent otherwise the test shall be repeated after 72 h. If the recovery after second test is less than 80 percent the structure shall be deemed to be unacceptable.

10.4.4 If prestressed, the recovery of maximum deflection should be at least 85 percent, otherwise test shall be repeated after 72 h. If the recovery after second test is less than 85 percent the structure shall be deemed to be unacceptable.

10.4.5 If the maximum deflection in mm, shown during 24 h under load is less than 40 L^2/D, where L is the effective span in m; and D is the overall depth of the section in mm, it is not necessary for the recovery to be measured and the recovery provisions of **10.5.3** and **10.5.4** shall not apply.

10.4.6 *Testing of Connection/Joint and System*

10.4.6.1 Monotonic test shall be carried out for beam-column /walls-slab/ wall-wall joints to quantifying the static behaviour.

10.4.6.2 Reverse cyclical load simulation test under intended loads of beam-column /wall-slab/ wall-wall joints, shall be carried out for quantifying the energy dissipation and hysteresis behaviour.

10.4.6.3 System level testing shall be carried out for every unique arrangement, if required by the contract or specification.

10.4.6.4 Testing shall be carried out in reputed Institutes with appropriate requirements.

10.4.6.5 Acceptance criteria for such test should be mutually established by the authority and the academic institution.

10.5 Testing for Water Tightness

10.5.1 External Precast Wall/Facade Panels

Any of the testing procedures given in **10.5.1.1** and **10.5.1.2** may be followed for testing of external wall/facade panel joints for water tightness.

10.5.1.1 *Testing procedure 1*

10.5.1.1.1 *General*

If it is deemed necessary to demonstrate that the precast facade joints are adequate to resist water penetration, a water penetration test on a full-scale panel including joint mock-ups may be undertaken.

10.5.1.1.2 *Test procedures*

Mock-up panels to be tested for water tightness should be subjected to both static and cyclic pressure in accordance with standard accepted procedures. Available international testing procedures are to be modified for local conditions as follows:

a) Differential test pressure shall be 20 percent of the maximum inward design wind load but not less than 0.77 kPa, and
b) The test shall be performed with a water flow rate of 3.4 litters/min/m^2 for 15 min.

10.5.1.1.3 *Sampling for a water penetration test*

Full-scale water tightness testing on precast facade panels and joints should be carried out at the rate of 0.5 percent for each type of joint and combination of panels or one for each type of joint and precast unit, whichever is greater.

10.5.1.1.4 *Failure criterion*

The facade units or joints are deemed to have failed, if signs of water seepage through the joints or through the facade unit, including signs of damp patches, are observed during the test or within the subsequent 2 h after the test.

10.5.1.1.5 *Remedial action on failure*

Upon failure of a water penetration test on a precast facade system the cause of failure should be identified and the system revised and re-tested until a satisfactory test result is achieved. Modifications shall be realistic in terms of job conditions and shall maintain standards of quality and durability.

10.5.1.2 *Testing procedure 2*

10.5.1.2.1 For external walls, a continuous jet of water shall be sprayed on the joint corresponding to 600 litres/h from a water hose having a nozzle velocity of 2 m/s and a cone scatter of approximately 60° held at a distance of 1.2 m from the wall surface under test. The duration of the test shall not be less than 2 h. The hose shall be placed centred on the horizontal or vertical joint width. For external walls, the following tests shall be conducted for each building block as per Table 17:

Table 17 Frequency of Tests for Vertical and Horizontal Joints
(*Clause* 10.5.1.2.1)

Sl No.	Building Height	Frequency of Tests
(1)	(2)	(3)
i)	Up to 10 storeys	5
ii)	Up to 20 storeys	10
iii)	Up to 30 storeys	15
iv)	Up to 40 storeys	20
v)	Up to 50 storeys	25

10.5.1.2.2 Twenty percent of these tests shall be carried out at the intersection of the vertical and horizontal joint.

10.5.1.2.3 These tests shall be carried out at any location as instructed by the Engineer-In-Charge.

10.5.1.2.4 *Acceptance criterion*

Water shall not seep into any part of the building during the test.

10.5.1.2.5 *Remedial action on failure*

For each test that fails, the tested joint shall be repaired as per the approved repair procedure as directed by the Engineer-in-Charge and the joint shall be retested for performance as per acceptance criterion. Two additional joints should be tested for each failed joint unless directed otherwise by the Engineer-in-Charge.

10.5.2 *Floor or Roof Slabs, Toilet Units and Kitchen Units*

10.5.2.1 A total of 5 percent of all horizontal floor and roof slabs area, including bathroom/toilet floors, kitchen floors shall be tested for water tightness for period of 4 h by ponding water. This test shall be carried out before floor finish or tiling operation. The depth of water ponding shall be maximum of the following:

a) At least 25 mm;
b) 10 mm more than thickness of joint;

10.5.2.2 *Acceptance criteria*

Water shall not seep into any part of the building during the test and after 24 h. The rooms below the tested room shall not show any water leakage. Minor dampness or seepage without dripping water in limited area of less than approximately 50 cm^2 is considered acceptable at a few areas and should be repaired suitable to avoid seepage. In any other cases, the test should be repeated per **10.5.2.3**.

10.5.2.3 *Remedial action on failure*

For each test which fails, the tested joint shall be repaired as per the approved repair procedure as directed by Engineer-in-Charge and the joint shall be retested for water tightness. Two additional joints/areas should be tested for each failed joint unless directed otherwise by the Engineer-in-Charge.

ANNEX A

(*Clauses* 4.5.2 *and* F-6.2.2)

GUIDELINE FOR 3D PRINTED CONCRETE STRUCTURES

A-1 GENERAL

This Annex provides an understanding of the materials, methods, and tests involved in concrete construction using 3D printing for different applications. This annex outlines the guidelines based on the current knowledge of 3D Printed Concrete Construction. However, in addition to this guideline, it is advised to refer to the applicable existing codes of practise and relevant research publications. Ongoing research, both in India and abroad, will result in the generation of the relevant design-related data, which can then be used for standardization.

A-2 METHODOLOGY AND SCOPE

The following points are considered while defining the application and performance guidelines:

a) *Printing Technique* – This document considers only extrusion-based 3D printing technology, where layers are deposited one over the other to construct a structure.

b) *Design Freedom* – 3D printing allows for flexibility in the geometry and form. The shape, size, and topology of any 3D printed concrete element for any application shall not be restricted. However, the performance requirements for 3D printing need to be satisfied.

c) *Material* – The material shall be printable and buildable. As per the current state of knowledge of concrete for 3D printing, the limits on the usage of cementitious materials in standard codes such as good practice [6-7(6)] would not be applicable for 3D printed concrete. The assessment of 3D printability of any concrete mixture needs to be carried out as per the available specialized literature on the subject. The mechanical, durability, and long-term properties of the printable material shall be measured as appropriate. In the absence of a clear understanding of the specimen preparation process for such tests, specialized literature can be used. The test program shall be conducted at NABL certified or Government laboratories and approved by statutory bodies.

d) *Performance Criteria* – The performance criteria of any 3D printed components shall conform to the existing Indian standards for equivalent components. In the absence of any standards, an experiment-based approach shall be followed to satisfy the requirements for the specific element or component.

e) *Special Applications* – In the absence of any standards, the engineer in charge of satisfying the qualification requirement as per Indian standards shall make decisions based on logical reasoning and practical evidence. The test program shall be conducted at NABL certified or Government laboratories and approved by statutory bodies.

A-3 APPLICATION – NON-LOAD BEARING

A-3.1 Falsework/ Formwork

3D-printed concrete may be used as stay-in-place (permanent) or temporary formwork for new concrete construction. The structural integrity of the formwork shall be either certified by a practicing structural engineer before the application or the formwork shall satisfy deformation limits and structural requirement mentioned in accepted standard [6-7(43)]. The formwork shall be designed by testing. The stay in place formwork shall not be considered as a part of the structural member.

A-3.2 3D Printed Concrete Building Blocks

The blocks can be solid as well as hollow, following the definition in accepted standard [6-7(44)]. The block's dimension shall have any external dimensions greater than the corresponding dimension of a brick as specified in accepted standard [6-7(45)]. The size and the mass shall be such as to permit it to be handled by one person. In case of mechanized placement of the blocks, larger units can be used. The height of the block shall not exceed either its length or six times its width. The faces of the block shall be manufactured based on the mutual agreement of the manufacturer and supplier/ purchaser. Accepted standard [6-7(44)] or any version with further amendment shall be followed for considering the tests required to satisfy the performance criteria of the blocks.

A-3.3 Autoclaved 3D Printed Blocks

The autoclaved 3D printed solid blocks shall be tested based on the requirements mentioned in accepted standard [6-7(46)]. The blocks can be of any dimension and shape while satisfying the need to permit them to be handled by one person. The face of the block need not be plain, and the design shall be decided mutually by the manufacturer and supplier/ purchaser.

A-3.4 Non-Load-Bearing 3D Printed Walls

3D printed concrete structures can be used as non-load bearing walls. The non-load-bearing walls can be divided into three types as mentioned as per Annex D of good practice [6-7(47)].

a) *Panel walls* – An exterior non-load-bearing wall in framed construction, wholly supported at each story but subjected to lateral loads.
b) *Curtain walls* – A non-load-bearing wall subject to lateral loads. It may be laterally supported by vertical or horizontal structural members, where necessary.
c) *Partition walls* – An interior non-load bearing wall, one storey or part storey in height.

Such walls can be assessed for the performance requirements in the given application, and if necessary, testing of individual elements with necessary connection details can be done to ascertain lateral load resistance and intended performance.

A-3.5 Precast 3D Printed Panels

Precast 3D printed panels can be used for external or internal non-load-bearing walls. The panels shall be connected considering the guidelines provided in good practice [6-7(48)]. The printing and erection tolerance shall follow the permissible limits mentioned in good practice [6-7(48)]. The designing of the wall panels (including reinforcement) shall be provided by a certified structural engineer using good practice [6-7(48)] or following the concept of design by testing (in the absence of standardized design methods).

A-3.6 External Facing and Veneers

3D printed components can be used for external facing following the guidelines mentioned in good practice [6-7(49)]. Precast-facing concrete blocks shall generally conform to the requirements of accepted standard [6-7(44)] and, in addition, shall have special treatment regarding durability, colour, and surface textures for the exposed facing. The face finish of slabs shall also be adequately waterproofed. The joint details, fixing technique, and method of attachment shall be provided by a certified structural engineer following the concept of design by testing, in the absence of standardized design methods.

A-3.7 Acoustic

The acoustic treatment of non-industrial buildings, industrial establishments, and cinema halls or conference rooms can be done using the design freedom provided by 3D printing. The incorporation of an air pocket between the inner and outer shell of a wall can help in the reduction of the transfer of noise between the rooms. The panel and partition walls can be printed with a suitable distance between face shells as suggested by good practice [6-7(50)]. The semi-discontinuous and discontinuous construction mentioned in the good practice [6-7(50)] can be followed for non-industrial buildings. For industrial establishments and cinema halls or conference rooms, the reverberation time governs the acoustic experience. Good practice [6-7(51)] (or any amended version of the same) shall be followed to determine the reverberation time required for each application. The face of the walls and ceilings can be designed to govern the reverberation time while satisfying the requirements in the standards mentioned.

A-4 APPLICATION – LOAD BEARING

A-4.1 Design Philosophy

3D printed concrete structure shall satisfy the strength as well as serviceability requirements. The scope of the code is limited to the load-bearing members in a building. Other structural applications are not considered for the purpose of this document. Additionally, the durability and long-term behaviour of the printed structure shall be considered during design.

The load-bearing walls consist of a 3D printed shell and cast in-situ reinforced concrete core. In these cases, the 3D printed shell is considered to act integrally with the core. Depending on the application and the loading, the requirement of the reinforced concrete core may be done away with – in other words, the shell itself is capable of handling the in plane and lateral loads.

The design of load bearing walls shall be dependent on the load resistance mechanism. For the following two applications, the design using available information, and based on established principles of analysis and deriving load resistance, as commonly used in established codes of practice may be followed.

a) If the load resistance is derived from cast in-situ reinforced concrete core, (*See* Fig. 42)

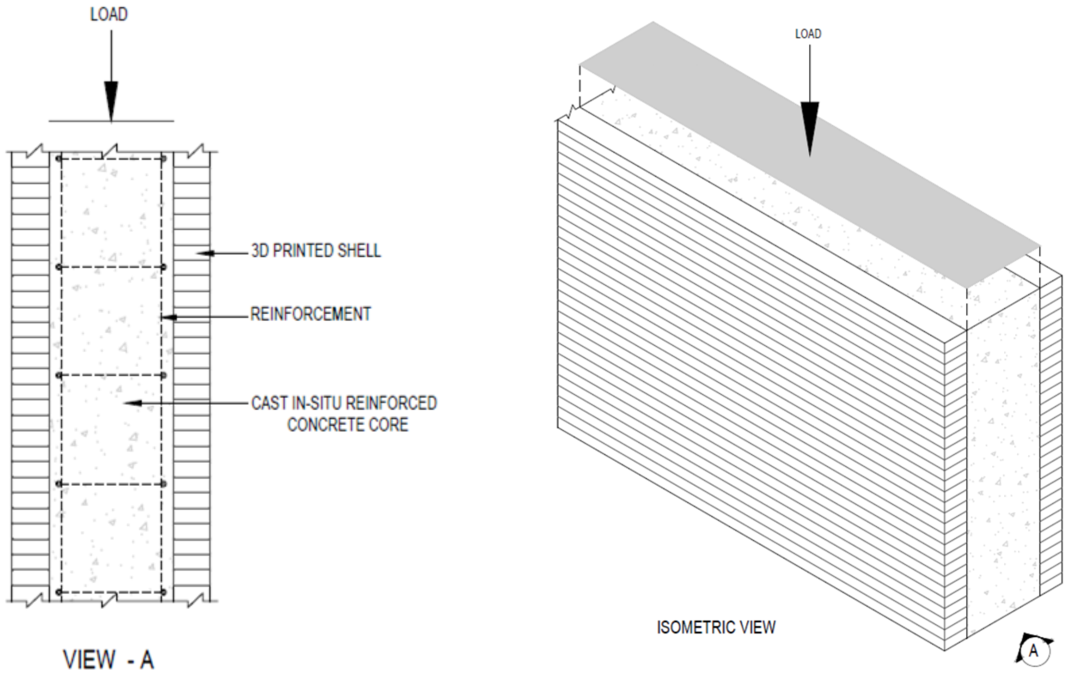


FIG. 42 LOAD RESISTANCE IS DERIVED FROM CAST IN-SITU REINFORCED CONCRETE CORE

b) If both 3D printed shell and cast in situ reinforced core are made using the same concrete mix, resulting in monolithic behaviour (*See* Fig. 43)

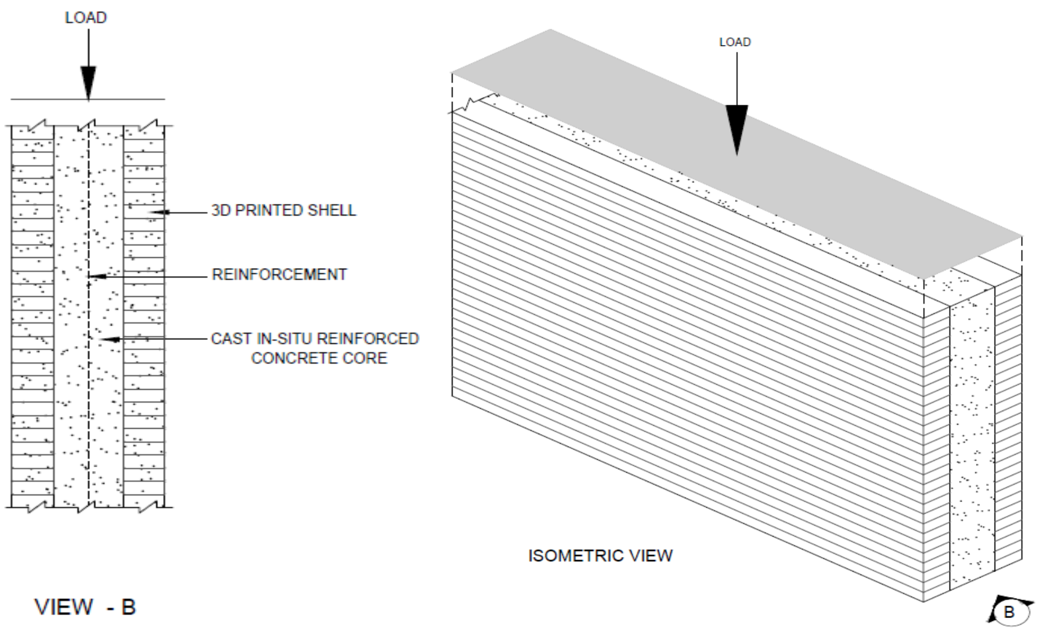


FIG. 43 LOAD RESISTANCE IS DERIVED FROM 3D PRINTED SHELL AND CAST IN-SITU REINFORCED CONCRETE CORE

Where load resistance is derived using composite action between printed shell and cast in-situ core, design by testing the individual components may be followed.

All attempts to make the printed object behave in a ductile manner should be made to the extent possible, irrespective of the nature of usage.

> NOTE- Special literature (AC 509 published by International Code Council (ICC)) may be referred while designing the test method for evaluation of the structural walls. Alternatively, load-bearing 3D printed structures can be constructed with suitable certification from government authorities (such as PACS from BMTPC).

Additionally, the structure shall comply all the requirements of good practice [6-7(52)] and any BIS code relevant to structural designing of buildings. The use of load bearing walls is limited to gravity load. The use for load resistance subjected to earthquake loading as per good practice [6-7(35)] and the requirements of ductile detailing as per good practice [6-7(1)] are outside the scope of this standard. Design by testing approach may be followed for any specific application.

A-4.2 Loads

The load criteria shall be as per the present codes. The lateral and earthquake load shall be taken special care of while designing the load bearing structures. The components of the structures shall be tested at full scale individual element level with necessary boundary conditions.

A-4.3 On-site and off-site construction

In case of an on-site construction, the printer is expected to be stationed at the location and construction to be carried out in-situ. For off-site construction, panels/ sub-parts of the structure are printed in a factory and assembled at the site. In such a case, particular attention is to be paid to the design of the connections, as per the prevailing standards and codes.

A-4.4 Load bearing wall

3D printed load bearing walls can be used for buildings up to a height where the effect of lateral load is not severe – this can be restricted to 12 m. For buildings beyond 12 m height, the structural design and construction methodology should be approved by statutory bodies. Special care shall be taken while designing the connection between wall to slab, wall to beam, and wall to footing. The minimum effective thickness of the load bearing wall shall be 100 mm following the guidelines of good practice [6-7(3)]. The 3D printed load bearing wall can be considered as:

a) 3D printed perimeter (with or without printed internal rib filaments) and cast in situ concrete core. Depending on the application and extent of loading, these walls can be fully solid (i.e. with the core completely filled with cast in situ reinforced concrete), hollow (i.e. without any internal filling) or partially filled (with reinforced concrete in some of the cavities).
b) Completely printed wall with no hollow space.

The cover depth of 3D printed wall shall consider exposure condition and fire resistance as per good practice [6-7(3)]. The cover depth should include the thickness of the 3D printed perimeter filament and the cover (if any) provided by the core concrete. The minimum reinforcement criteria laid by good practice [6-7(3)] shall be followed. Horizontal reinforcement in the form of high yield strength deformed (HYSD) rebar or welded wire mesh or textile mesh shall be provided to connect the outer leaves to the inner core, when the design assumes a composite action of the 3D printed perimeter and the inner core. In other cases, the printed leaves shall be considered as stay-in-place formwork and shall not be taken as a part of the load-bearing wall. However, even in such cases, efforts should be made to ensure that spalling or collapse of the outer periphery does not occur in extreme events such as earthquakes.

The walls shall satisfy the strength and serviceability criteria of the load bearing walls as per good practice [6-7(3)]. If required, the design shall be done by testing of individual elements with necessary boundary conditions or connection details. For testing guidelines, specialist literature and publication may be referred if necessary.

NOTE – Specialist literature/publication may include AC 509 published by International Code Council, etc.

A-4.5 Load bearing column

Column shall be designed using as per code of practice [6-7(3)]. If required, test results obtained by full scale testing of individual elements with necessary boundary conditions or connection details shall be used. Buckling load criteria shall be satisfied considering the end-restraint conditions by testing. A certified structural engineer shall design the column as per logical reasoning based on experimental evidence.

A-4.6 Shear walls

The shear walls shall be solid walls designed as per the requirements of good practice [6-7(3)] and [6-7(1)]. However, the design guidelines shall be similar to load-bearing 3D printed walls. The performance of 3D printed shear walls under lateral and earthquake load shall be tested. The design shall be done based on the experimental outcomes by a certified structural engineer.

A-4.7 Load-bearing beams and slabs

The 3D printed beam and slab shall satisfy the load and serviceability requirements mentioned in good practice [6-7(3)]. The flexural capacity of the printed beam shall be tested using 3-point and 4-point bending test at full-length-scale element level. The characteristic strength of the printable mix shall not be used to design the flexure member, rather, the results from full-length-scale element level tests shall be used. A certified structural engineer shall design the flexural members as per the reports from the testing.

A-4.8 Foundation

A 3D printed foundation shall be designed following the design by testing method. The foundation can be printed in-situ or assembled at site like precast foundation after printing at the factory. The foundation shall be designed by a certified structural engineer while considering inputs from geotechnical engineers about the soil bearing characteristics. Durability requirements, as mentioned in good practice [6-7(3)], for the foundation shall be strictly satisfied.

If the outer perimeter of the foundation is only printed and the core is cast as conventional foundation, then the printed part shall not be taken into the load calculation and shall be treated as a formwork.

A-4.9 Retaining wall and basement

Retaining wall and basement shall be solid for load-bearing applications. Reinforcement strategy shall follow the guidelines mentioned for 3D printed load bearing walls.

A-4.10 Rebar-concrete bond strength and development length

These are to be determined for each case and the structural engineer shall take into account the same while designing the reinforcement. The effect of layer time gap and moisture loss shall also be considered while designing the reinforcement. The bond between the rebar and the printed concrete shall be measured before designing the reinforcement.

A-4.11 Connections

Connections between the elements, including, but not limited to between two printed elements; printed non-structural element and cast in-situ structural reinforced concrete element; printed non-structural element and precast structural element; printed structural element and precast structural element; and printed structural element and printed structural element shall follow the requirements mentioned in good practice [6-7(53)]. If required, the connections shall be designed by testing. However, the connection between cast-in-situ reinforced core and other structural elements shall follow standard design practice.

A-5 OTHER APPLICATIONS

A-5.1 Boundary walls

3D-printed boundary walls shall follow the guidelines mentioned in Part 3 'Development Control Rules and General Building Requirements' of the Code of the Code. The 3D-printed boundary wall shall not be a retaining wall or any load-bearing structure.

A-5.2 Design elements for outdoor spaces

a) Pavement and other pedestrian movement spaces such as footpaths, plaza assembly spaces, kerb to footpath, steps, and ramps.
b) Parking and vehicular movement corridors such as road dividers, road marking, etc.
c) Traffic management units such as gate/ access control, barriers, traffic separators, etc.
d) Outdoor public conveniences such as seating, drinking fountains, toilet/washrooms, etc.
e) Shelter and kiosks such as bus shelters, police and telephone booth, food stall, information desk, etc.
f) Outdoor illumination such as street light pedestals, etc.
g) Tree guards, tree grates, and planters.
h) Litter bins, and spittoons.
j) Service utilities relating to water supply network, storm water network, sewerage system, irrigation network, etc.

These structures shall be designed by a certified structural engineer following the reports from experimental evaluation.

A-6 CURING

The printed structures shall be cured following the provisions mentioned in good practice [6-7(3)]. However, curing shall be initiated at the early age to avoid plastic shrinkage cracks. Water spraying in the form of a fine mist must be started even before the initial set. At any given instance, the surface shall not be dry. The curing shall be done until the designed strength is reached for the 3D printed walls and slabs. Curing compounds can be used to reduce the number of days of water curing. The engineer in charge shall take the decision regarding the curing requirements based on experimental evidence.

A-7 QUALITY ASSURANCE AND QUALITY CONTROL

The following properties shall be assessed for determining the quality of the 3D printable concrete mix. The sampling shall be done as per good practice [6-7(3)] or any amended version thereof.

The mechanical properties including cube compressive strength, elastic modulus, split tensile strength, and flexural strength of the concrete shall be tested following the guidelines mentioned in accepted standard [6-7(54)]. The properties of water permeability, drying shrinkage, and rapid chloride permeability shall also be tested following the relevant IS codes. The tests shall be performed on the specimens sawn/cored from printed samples. The anisotropy of the structure shall be tested along X, Y, and Z coordinates. The test shall be conducted on the cast specimen also with the concrete used for printing the structure.

Additionally, the bond strength of the layer shall be tested by extracting beam specimens of 40 × 40 × 160 from the printed structure, or a special test element. 3-point and 4-point bending test shall be performed on the extracted specimens with a minimum number of 5 specimens for each sample.

ANNEX B
(*Foreword and Clause 4.5.1*)

PREFABRICATED PREFINISHED VOLUMETRIC CONSTRUCTION (PPVC)

B-1 GENERAL

The objective of this document is to provide a comprehensive guideline on prefabricated prefinished volumetric construction (PPVC) methods, materials, design standards, and performance criteria for building professionals and stakeholders involved in modular construction. This document aims to facilitate the understanding and practical application of PPVC across various types of construction projects, including residential, commercial, and industrial buildings. By outlining the key requirements and standards, this annex supports efficient and effective PPVC project planning, production, and assembly to ensure high-quality, durable, and sustainable modular structures.

It provides insights into essential aspects of PPVC, such as design principles, manufacturing and installation practices, quality assurance, transportation, and site assembly. The annexure also encourages the adoption of best practices in PPVC by highlighting critical considerations for structural integrity, fire safety, environmental sustainability, and inspection protocols, supporting ongoing efforts to advance safe and innovative construction methods.

B-2 METHODOLOGY

The following points are considered while defining the application and performance guidelines:

B-2.1 Design

This document considers the architectural and structural planning of PPVC modules, considering modularization, alignment, and standardization of dimensions. It ensures the modules meet specifications for efficient on-site assembly, structural integrity, and compliance with building codes and design requirements.

B-2.2 Off-Site Manufacturing

The modules should be constructed in a controlled factory environment. This allows precise manufacturing with minimal errors and faster production times. Components, including concrete and steel modules, are cast, cured, and finished with necessary fixtures, plumbing, and electrical setups before transport.

B-2.3 Transportation

Once manufactured, modules are carefully transported to the construction site. The transportation plan ensures that modules remain undamaged and conform to transportation regulations, accounting for dimensions, weight, and route restrictions.

B-2.4 On-Site Assembly

This final stage involves installing and connecting the modules at the construction site. Modules are hoisted and secured in place, followed by finishing work, such as joint sealing and final inspections, ensuring the assembled structure meets all quality and safety standards.

B-2.5 Modular Dimensions

PPVC modules should designed to fit within standard transportation limits to ensure easy delivery to construction sites. Common dimensions range from 3 m to 12 m in length, 2.5 m to 3.5 m in width, and 2.5 m to 4.5 m in height. Specific adaptations shall account for the maximum width (2.5 m), height (4.5 m including truck height), and length (up to 18 m) based on transportation guideline.

B-2.6 Transportability and Site Constraints

Module size and weight are also influenced by on-site access, route clearance, and crane requirements. The structure should be modularized to ensure efficient on-site alignment and joining of the modules while reducing the need for additional site handling

B-2.7 Materials

a) *Concrete and Steel Modules* – PPVC modules are typically constructed from high-performance materials like reinforced concrete (RC) or steel. Reinforced concrete offers durability and structural integrity, whereas steel provides a lighter alternative, especially useful for high-rise buildings.

b) *Enhanced Material Specifications* – Materials are chosen for performance under factory conditions and transportation stresses. For instance, high-strength/performance concrete (HPC) and steel conforming to relevant Indian Standard (such as Fe 500 or higher for reinforcement) are preferred. The use of sustainable materials, such as fly ash and other admixtures, is also encouraged to improve durability and reduce environmental impact.

B-2.8 Connections

Connections shall be strong enough to secure modules under various stresses, including lifting, transportation, and environmental forces. Common PPVC connection methods include grouted couplers, wire loop boxes, dowel systems, and mechanical fasteners. These ensure that modules are securely integrated without compromising flexibility needed for seismic or wind forces.

Vertical joints (for stacking modules) and horizontal connections (for lateral stability) are essential for PPVC structures. These connections often involve interlocking systems or bolted end plates that provide stability while allowing for some movement to accommodate load and environmental stresses.

Connections should be designed to follow the Indian Standards for seismic and wind loads, such as good practice [6-7(55)], to ensure safety and resilience under local conditions. Proper connection systems are necessary to transfer loads between modules and secure them as a unified structure.

B-2.9 Alignment

The alignment of prefabricated prefinished volumetric construction (PPVC) modules is critical to ensure that the final building is structurally sound and aesthetically pleasing. There are several key considerations to keep in mind when aligning PPVC modules:

a) The foundation on which the PPVC modules are placed should be level and square. If the foundation is not level, it can cause the modules to shift and potentially compromise the structural integrity of the building. Unless it is designed as a paper joint, a minimum 20 mm joint thickness shall be detailed between the top of the foundation and the PPVC module to account for site tolerances. The joint shall be later grouted with high strength grout per design specification for structural integrity as well as continuity for functional performance.
b) Each PPVC module should be precisely aligned with the adjacent modules to ensure that the building is straight and true. This is typically achieved using alignment pins or other methods to ensure that the modules are aligned both vertically and horizontally. The erection tolerances shall be followed per **8.7.5**.
c) Ensuring that the PPVC modules are level vertically is also critical to the structural integrity of the building. Laser levels and other tools can be used to ensure that the modules are plumb and aligned with the adjacent modules.
d) The facade of the building, which includes windows, doors, and exterior finishes, shall also be precisely aligned with the PPVC modules to ensure that the final building looks aesthetically pleasing.

B-2.10 Structural Design and Load Compliance

PPVC modules shall comply with load standards as outlined in good practice [6-7(21)], which address dead loads, live loads, wind loads, and other special loads. Modules should also meet seismic design requirements under good practice [6-7(25)] to ensure stability during earthquakes.

Structural elements for concrete and steel structures shall follow the good practice [6-7(56)], ensuring that all modules meet load-bearing and durability criteria. The Limit State Method is typically applied for PPVC modules, which includes safety factors to manage risks associated with live loads, dead loads, and extreme environmental forces.

B-2.11 Material Standards

a) *Concrete and Reinforcement Compliance* – For concrete quality, PPVC construction follows good practice [6-7(3)] for concrete standards, including high-performance concrete or self-compacting concrete for durability. Reinforcements use deformed steel bars as per accepted standard [6-7(57)] for high-strength requirements, ensuring modules can withstand handling, transport, and on-site stresses.

b) *Admixtures and Aggregates* – Chemical and mineral admixtures shall comply with accepted standards [6-7(5)], which specify performance standards for durability and workability. Aggregates are selected as per accepted standard [6-7(58)], ensuring strength and proper gradation.

B-2.12 Fire Safety and Compartmentation

Fire Resistance: PPVC structures shall comply with NBC's Fire and Life Safety Codes, specifying compartmentalization and fire-resistant materials as per good practice [6-7(3)] and additional fire safety guidelines. Each PPVC unit shall be designed with fire-rated walls, floors, and doors to contain fire and smoke spread, providing adequate escape routes and protection for occupants.

Material Fire Compliance – All materials used shall meet good practice [6-7(42)] for fire safety, ensuring that structural elements are designed to withstand high temperatures. Fire compartmentation as outlined by Part 4 of the Code mandates that modules above certain heights include additional fire barriers and safe egress routes.

B-2.13 MEP (Mechanical, Electrical, Plumbing) Standards

a) *Electrical Systems Compliance* – Electrical installations in PPVC buildings should meet the accepted standard [6-7(59)], ensuring safe and reliable connections between modules. Additionally, accepted standard [6-7(60)] should be used for lightning protection systems to prevent electrical hazards.

b) *Plumbing and Sanitation* – Plumbing systems follow good practice [6-7(61)] standards for water supply and drainage, ensuring leak-proof, pressure-resistant pipes that meet durability and sanitation requirements in modular installations.

B-2.14 Construction Tolerances

Construction tolerance limits in prefabricated prefinished volumetric construction (PPVC) refer to the allowable deviation from the intended design and specified dimensions. These limits are important to ensure that the final building is structurally sound and aesthetically pleasing. The construction tolerance limit in PPVC can vary depending on the specific materials and construction techniques used, as well as the local building codes and regulations. Permissible tolerances from the specified dimension of a PPVC module shall conform to casting tolerances provided in **8.7.5**.

B-2.15 Performance Criteria

The performance criteria of any PPVC components shall conform to the relevant Indian Standard for equivalent components. In the absence of any Indian Standard, the safety and durability of the specific element or component shall be demonstrated through testing.

B-2.16 Special Applications

In the absence of any standards, the engineer in charge shall make decisions based on logical reasoning and practical evidence. The test program shall be conducted at NABL certified or Government laboratories and approved by statutory bodies.

B-3 APPLICATIONS

B-3.1 Residential and Commercial Buildings

PPVC modules for residential and commercial buildings can be used in multi-storey structures, designed as either load-bearing or non-load-bearing units. Load-bearing modules, which support vertical loads, shall meet the structural criteria for stability and safety in multi-level configurations, while non-load-bearing modules serve as partitions or infill components. Good practice [6-7(29)] (for fire safety) and good practice [6-7(47)] (for structural masonry requirements) guide fire resistance, sound insulation, and seismic load-bearing capacities to meet safety standards. Engineering design shall ensure proper connections and integration to create a cohesive and compliant structure.

B-3.2 Educational and Healthcare Facilities

For educational and healthcare facilities, PPVC applications shall adhere to specific regulatory and spatial requirements outlined in Part 3 'Development Control Rules and General Building Requirements' of the Code for public and healthcare buildings. Modules are pre-finished to meet spatial needs, such as classrooms and patient areas, integrating critical systems like mechanical, electrical, and plumbing (MEP) per good practice [6-7(62)] (for water supply) and good practice [6-7(63)] (for plumbing in multi-storey buildings).

B-3.3 Industrial Buildings

PPVC in industrial buildings such as warehouses and factories requires modules engineered to meet the load-bearing and lateral resistance standards outlined in good practices [6-7(33)] (for structural steel) and good practice [6-7(3)] (for reinforced concrete). The modular units allow for open, high-capacity spaces that can bear substantial loads, with compliance to good practice [6-7(21)] (for design loads, wind and snow loads) and good practice [6-7(25)] for seismic considerations. Structural configurations shall also align with fire safety standards {good practice [6-7(29)]} and facilitate efficient integration of services. This approach enables high-speed assembly, structural integrity, and durability for industrial purposes while meeting all IS code requirements.

B-3.4 Design Philosophy

PPVC structures shall be designed to meet strength and serviceability requirements, ensuring structural integrity under the anticipated loads. This document focuses on load-bearing applications within PPVC, excluding non-structural or purely aesthetic uses. Additionally, the design shall account for durability and long-term performance, particularly as modules are prefabricated off-site and subjected to transportation and on-site assembly stresses.

Load-bearing PPVC modules typically consist of a reinforced concrete or steel core surrounded by a prefinished volumetric structure. This core provides essential stability, especially under vertical and lateral loads. In certain applications, the volumetric shell itself may be designed to carry both in-plane and lateral loads, with the core providing additional structural redundancy.

The design approach for load-bearing PPVC modules shall depend on the load resistance mechanism employed, as outlined below:

a) *Core-Based Load Resistance* – Where the primary load resistance is provided by a reinforced concrete or steel core, which may be cast in-situ or prefabricated.

b) *Monolithic Module Design* – Where the PPVC module's core and shell use a compatible concrete mix or reinforcement design to behave as a single monolithic unit under load.

For cases where the load resistance is derived from the combined action of the volumetric shell and the core, individual component testing is recommended to validate the composite action. Efforts to promote ductile behaviour are essential, ensuring that load-bearing PPVC elements respond safely under stress.

NOTE- Testing and certification can be carried out as per specialised literature (reference AC 509 by the International Code Council (ICC) for structural evaluation methods), or structures may be certified through recognized government bodies such as BMTPC in India. Compliance with good practice [6-7(52)] and other applicable BIS standards is mandatory for structural design. The scope here is limited to gravity loads; resistance to earthquake-induced forces and ductile detailing as per good practice [6-7(25)] and [6-7(1)] may require additional testing and validation.

B-3.5 Loads

Load criteria for PPVC modules shall conform to good practices, with particular attention to lateral and seismic loads. Structural components shall be validated through full-scale testing of individual elements, ensuring that boundary conditions mimic real-world applications. Testing shall confirm that PPVC modules meet all load-bearing and serviceability requirements, as specified accepted standards, for safe deployment in permanent structures.

B-3.6 Foundations

A PPVC foundation shall be designed following a design-by-testing approach to confirm compliance with all load-bearing and durability standards. The foundation may be cast in-situ or prefabricated off-site as a precast unit for on-site assembly. Design shall be overseen by a certified structural engineer, with essential geotechnical input to evaluate soil bearing capacity, ensuring that the foundation is appropriate for the specific site conditions. Durability requirements per good practice [6-7(3)] shall be strictly observed to maintain long-term performance and stability under applied loads.

To ensure a secure connection between the PPVC modules and the foundation, appropriate dowel bars or reinforcement shall be incorporated into the foundation design. These reinforcement provisions shall align with the load transfer requirements and provide structural continuity between the foundation and the modular components. Proper anchorage and placement of dowels will prevent differential movement and provide stability for the assembled structure.

B-4 CURING

As PPVC modules are manufactured in an off-site, controlled environment, advanced curing methods may be implemented to expedite the process and ensure consistent quality. In addition to following good practice [6-7(3)] standards, rapid curing techniques, such as steam curing, warm water curing, or the use of curing compounds, can be employed to accelerate strength development. These methods enable the modules to achieve the desired performance levels within a shorter time frame, which is critical for modular construction timelines.

The curing approach should ensure that modules reach their designed strength before transportation to the construction site. The decision on curing methods and duration should be based on testing and performance requirements, as determined by the supervising engineer, to guarantee durability and structural integrity.

B-5 QUALITY ASSURANCE AND QUALITY CONTROL

Compliance with good practices includes ongoing quality checks at both the manufacturing and construction stages. Regular inspections, as per NBC and IS standards, verify structural integrity, alignment, and safety of each module, especially focusing on connections and material durability over time.

B-6 MAINTENANCE AND INSPECTION

Regular inspection and maintenance protocols should be set to identify wear or structural concerns in connections and external finishes, ensuring longevity and safety as outlined in NBC guidelines.

ANNEX C
(*Clause* 4.5.3)

GUIDELINES FOR DESIGN FOR MANUFACTURING AND ASSEMBLY (DFMA)

C-1 The concept of design for manufacturing and assembly (DFMA) emphasizes the use of precast and prefabricated building components. The underlying principles of DFMA call for more efficient building design and construction detailing, especially in the area of Precast Concrete connection designs, so as to minimize the amount of wet works on-site.

To develop an advanced pre-cast concrete system (APCS), it is important for the various building disciplines to first understand the functional considerations, building aesthetics, and design approaches. This understanding will then inform the conceptualization and development of the APCS design, ensuring it meets the project specifications. It is essential that the APCS design is coordinated with the manufacturing specification for components, construction planning, and site work to ensure seamless integration and efficient construction processes.

C-2 DESIGN BASIS FOR ADVANCED PRECAST CONCRETE

The following are key principles of efficient construction using APCS systems:

a) *Modular Architecture Layouts* – designing buildings in modules to allow for greater use of precast and prefabricated components, reducing on-site construction time and costs.
b) *Precast Repetition* – using standard precast elements repeatedly throughout the building, simplifying the construction process and reducing the need for customization.
c) *Efficient Structural Design* – Detailing (Standardize design and detailing) – designing precast connections that can be easily assembled on-site, reducing the need for wet works and temporary supports.
d) *Quick Assembly Detailing* – designing connections and components that can be quickly and easily assembled on-site, reducing construction time and costs.
e) *Limited Use of Temporary Supports* – designing precast components that can be assembled without the need for temporary supports, further reducing construction time and costs.

C-3 FACADE STANDARDIZATION

Architectural design is a process to create a built environment with functionality for human comfort and sustainability through art and engineering design. In an effective PC construction, the external facade design is generally achieved through optimal standardization in the following:

a) *Shapes* – FRP/rubber-lined moulds can be used to create various shapes for precast concrete components.
b) Textures such as sandblasted or acid-etched finishes can also be added to enhance the visual appearance of the precast components.

c) Different colours can be achieved using pigments or concrete colours, allowing for a wide range of design options.
d) *Repetition* – Standard precast elements can be repeated throughout a building's facade, making construction faster and more efficient.
e) *Modular design* – It allows for the precast components to be easily assembled on-site, reducing the need for wet works and temporary supports.
f) Small complex facade panels: Glass Reinforced Concrete (GRC) can be used instead of concrete for small complex facade panels.
g) *Complex facade as a separate add-on* – Complex facade elements can be designed and manufactured separately from the building structure, allowing for easier handling and installation on-site.
h) *Layouts rotated over mirrored* – Rotating layouts over mirrored elements can make use of the same assembly for construction.
j) *Checklists* – Checklists can be used to ensure good precast arch design, covering aspects such as structural integrity, aesthetic appeal, and ease of construction.

C-4 STRUCTURAL DESIGN

Structural design has a direct impact on the ease of PC manufacturing and site erection works. The key consideration for structural system design solutions are:

a) *Simple Design and Detailing* – Precast concrete components should be designed with simple connections that can be easily assembled on-site, reducing construction time and costs.
b) *Commercial - Long Spans* – Precast concrete components can be used for long-span commercial buildings, such as warehouses or shopping centres.
c) *High Rise Residential* – In high-rise residential buildings, precast concrete wall panels can be used in conjunction with precast concrete floor slabs.
d) *Low/Mid Rise Residential* – In low to mid-rise residential buildings, precast concrete wall panels can be used with precast concrete floor slabs and beam-column combinations.
e) *Design to Cater for Temporary Loads during Construction* – The structural design should cater for temporary loads during the construction phase, such as the weight of equipment and construction workers.

C-5 TYPES OF STRUCTURAL SYSTEMS

All semi or full PC structural systems need clear consideration for stability. It may take one of the following forms:

a) *Skeletal Frames* – Precast concrete components can be used to create skeletal frames, with columns and beams connected with precast framed connections.
b) *Load Bearing Walls* – Precast concrete wall panels can be used as load-bearing walls, supporting the weight of the floors and roof.
c) *Load Bearing Facade* – In a load-bearing facade system, the precast facade concrete panels bear the weight of the building and transfer the loads to the foundation independently to the core of the structure.
d) *3-D Boxes* – Precast concrete components can be used to create 3-D boxes, with precast walls, floors, and roofs forming the 3-D building unit.

e) *Mixed Systems* – A combination of precast concrete components can be used to create mixed systems, such as precast concrete walls with cast-in-place concrete floors.
f) *Checklists for Good Precast Structural Design* – Checklists can be used to ensure good precast structural design, covering aspects such as strength and durability, fire resistance, seismic design, and ease of construction.

C-6 CONNECTIONS

Connection in PC construction must be designed to take the forces derived in the structural modelling. To achieve work efficiency, the design approach should consider the following aspects:

a) *Standardized* – Standardized precast concrete connections are designed to be easily designed, manufactured and assembled on-site.
b) *Ease of Erection* – Precast concrete connections should be designed with ease of erection in mind, to ensure that they can be quickly and safely assembled on-site.
c) *Simple and Minimalistic* – Simple and minimalistic connections are preferred in precast concrete construction, as they are more efficient and cost-effective.
d) *Checklists for Good Connection Systems* – Checklists can be used to ensure good precast concrete connection systems, covering aspects such as durability, strength, and ease of assembly.
e) *Innovative Connections* – Innovative precast concrete connections can be used to create unique and complex structures, such as hybrid steel and precast systems or lotus root precast systems. These connections can offer advantages such as improved structural performance, and reduced construction time.

C-7 DESIGN OF CONNECTIONS

Design methods for joints in precast construction have been covered by various international technical journals and published academic research papers. They briefly cover the connections listed below:

a) *Corbel-Beam End Joint* – A hidden mechanical connector can be used for the corbel-beam end joint, similar to hanger connections.
b) *Column/Wall Base Mechanical Connections* – Column shoes and wall shoes with anchor bolts can be used for mechanical connections at the base of columns and walls.
c) *Wall to Wall Connections* – Wire loops can be used for wall to wall connections.
d) *Beam to Beam* – Steel hangers can be used for connecting precast concrete beams.
e) *Rigid Beam-Column* – Top steel couplers and bottom steel welded connections can be used for rigid beam-column connections, ensuring that the connection is strong and can resist bending and shear forces.

C-8 CONNECTION DESIGN CONCEPT

a) Load Paths – Diaphragm, Slab to wall/column paths, slab-beam shear connection,

b) Frame behaviours
c) Accidental loads, progressive collapse
d) Tie Design forces – Similar to IS, Column/Wall ties is new
e) Tie continuity – Laps, tie with enclosed links
f) Tie anchorages with other ties

C-9 DESIGN EXAMPLES

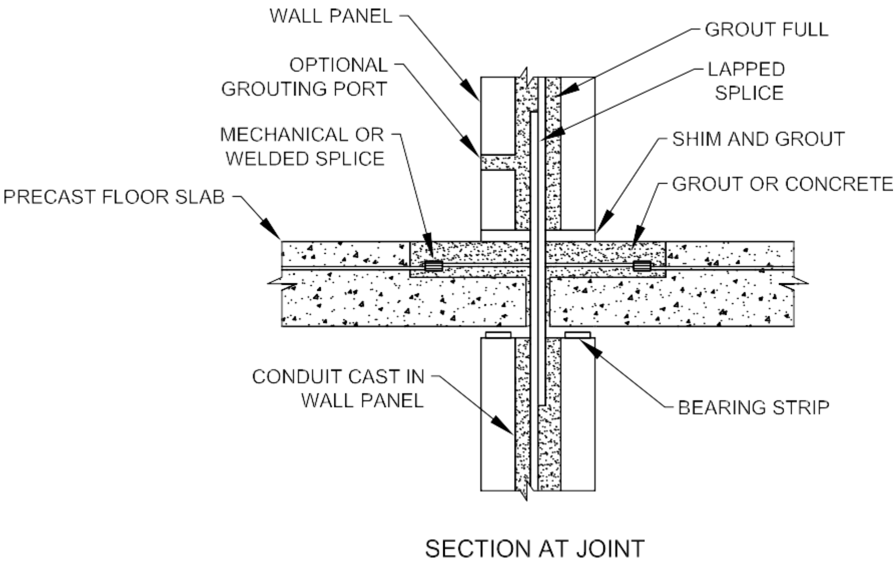
a) Beam Half Joint (Dap Connection)
b) Beam Half Joint (Hanger/Beam Shoe Connection)
c) Corbel (Conventional)
d) Peikko Corbel
e) Column Base – Splice Sleeve/Grouted Couplers
f) Column Base – Shoe Connection
g) Wall Base – Splice Sleeve/Grouted Couplers
h) Wall Base – Shoe Connection
j) Wall – Wall Joint – Shear Keys only
k) Wall – Wall Joint – With Loop reinforcement
m) Beam Steel Hangers – Generic
n) Beam Steel Hangers – Peikko
p) Proprietary Mechanical connections
q) Column to base and Column to Column
r) Beam to Column – Moment connection
s) Beam to Column – Simply supported
t) Beam to Beam
u) Wall to Wall – Vertical and Horizontal connections
v) Landing Slabs – TSS

ANNEX D

(*Clauses* 6.3 *and* A-3.4)

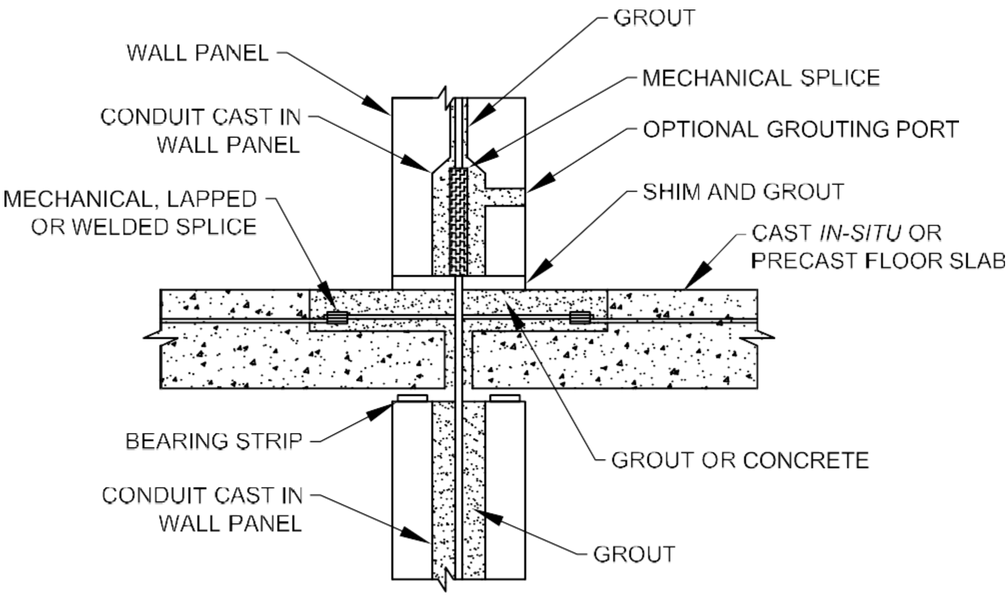
COMMON PRECAST CONNECTIONS

D-1 Typical figures of some common precast joint connections are given in Fig. 44 to Fig. 60.



NOTE – Overlapping bars in grout-filled conduit are extended full-height through the structural element

FIG. 44 LAPPED SPLICES IN LARGE CONDUIT



NOTE – Vertical bars in conduit are spliced and the system is grouted

FIG. 45 MECHANICAL CONNECTION IN CONDUIT

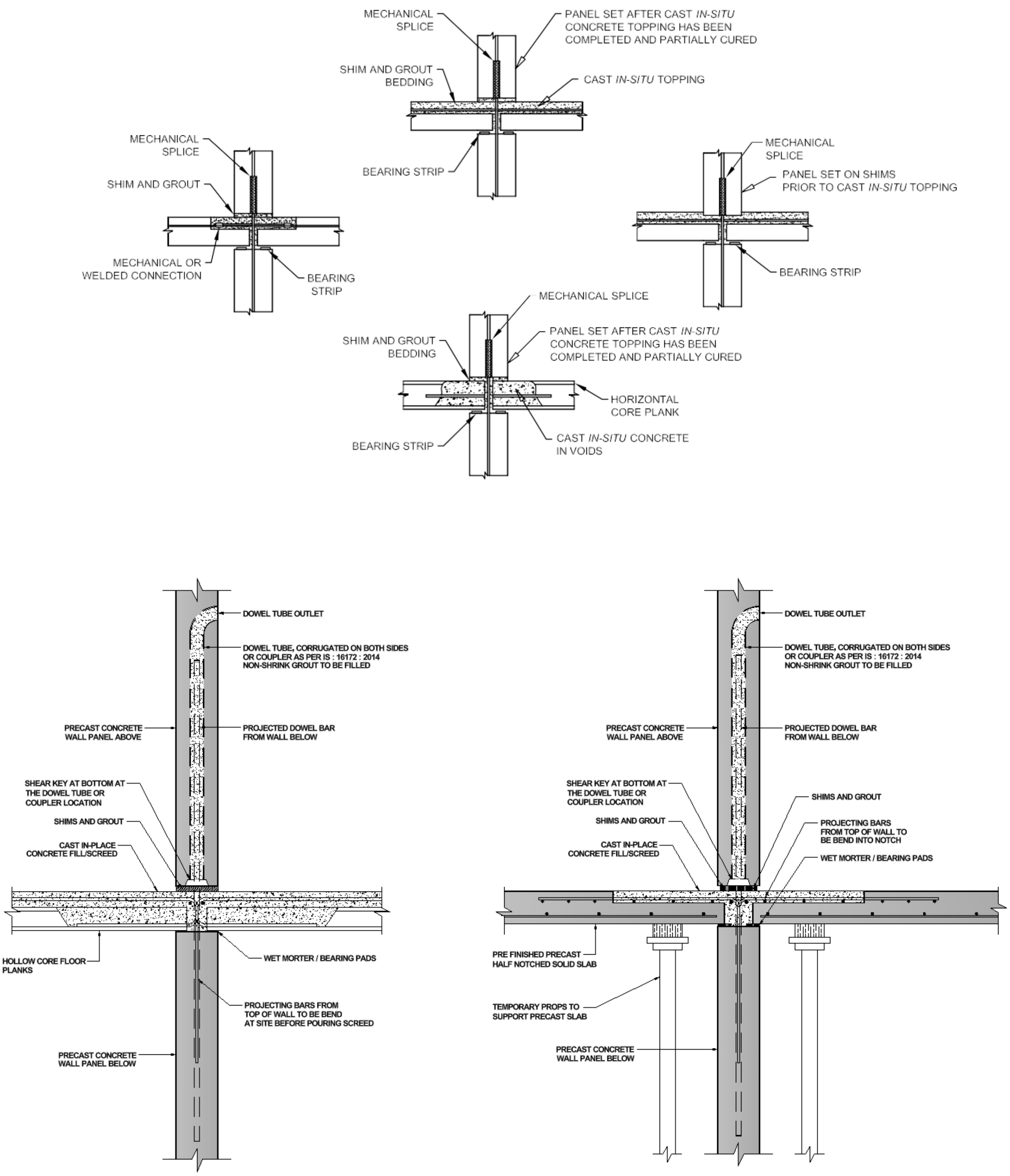


FIG. 46 DIFFERENT TYPES OF MECHANICAL SPLICES FOR CONNECTION OF VARIOUS CONFIGURATIONS OF PRECAST WALL AND FLOORS

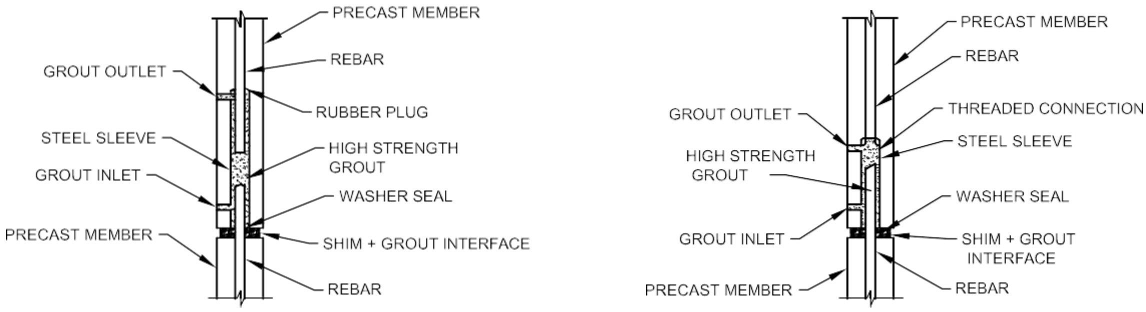
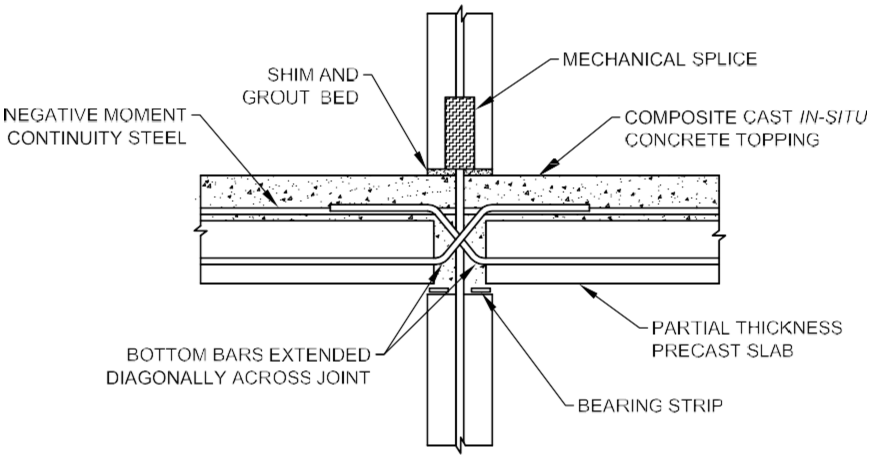
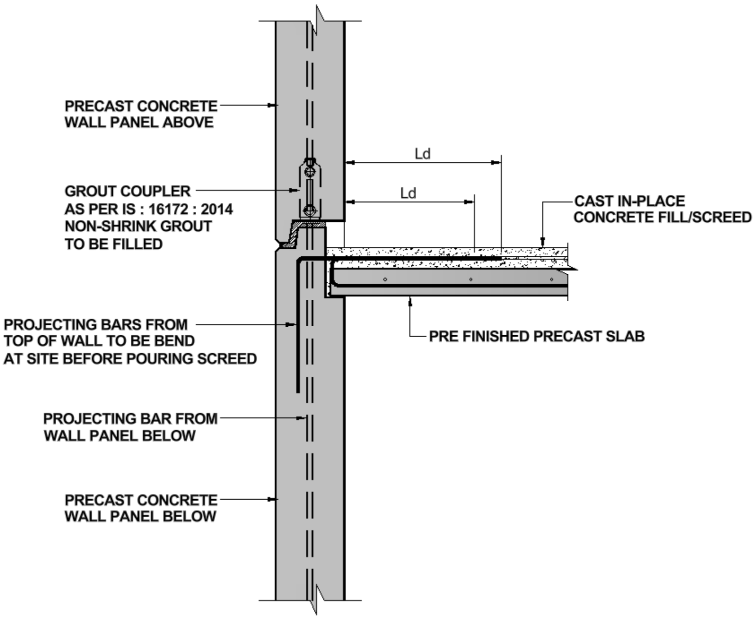


FIG. 47 MECHANICAL SPLICES USING HIGH-STRENGTH NON-SHRINK NON-METALLIC GROUT

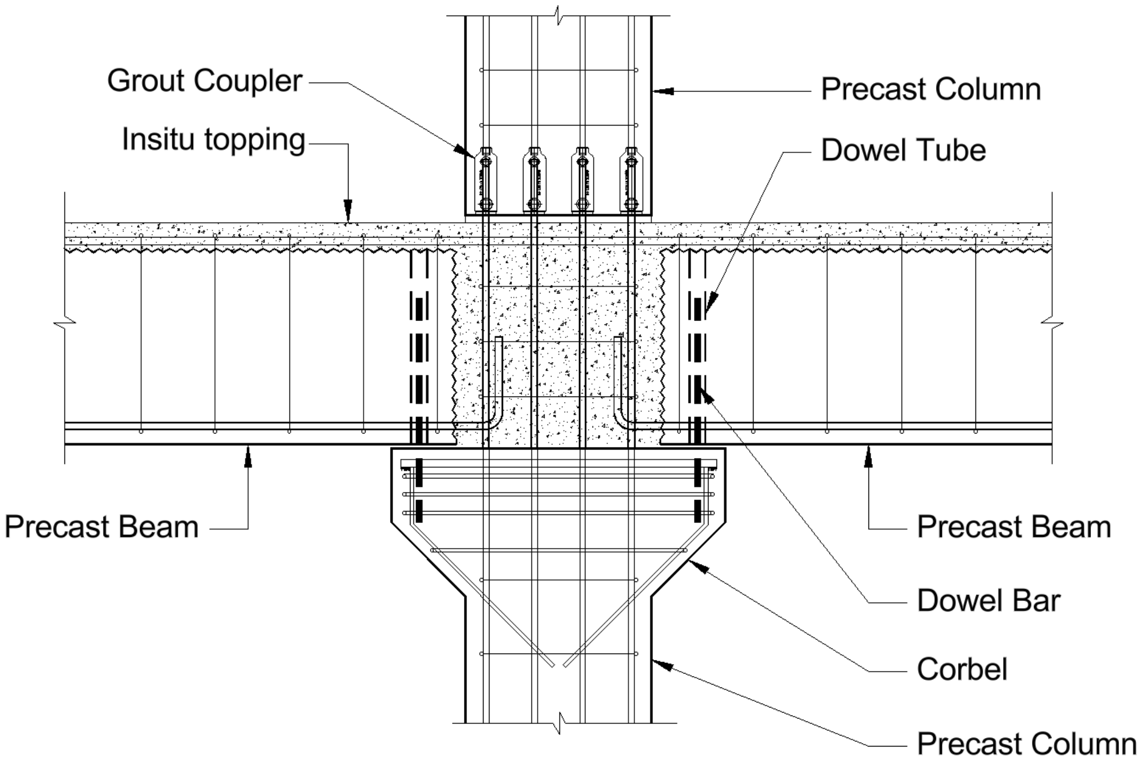


48A Central Wall

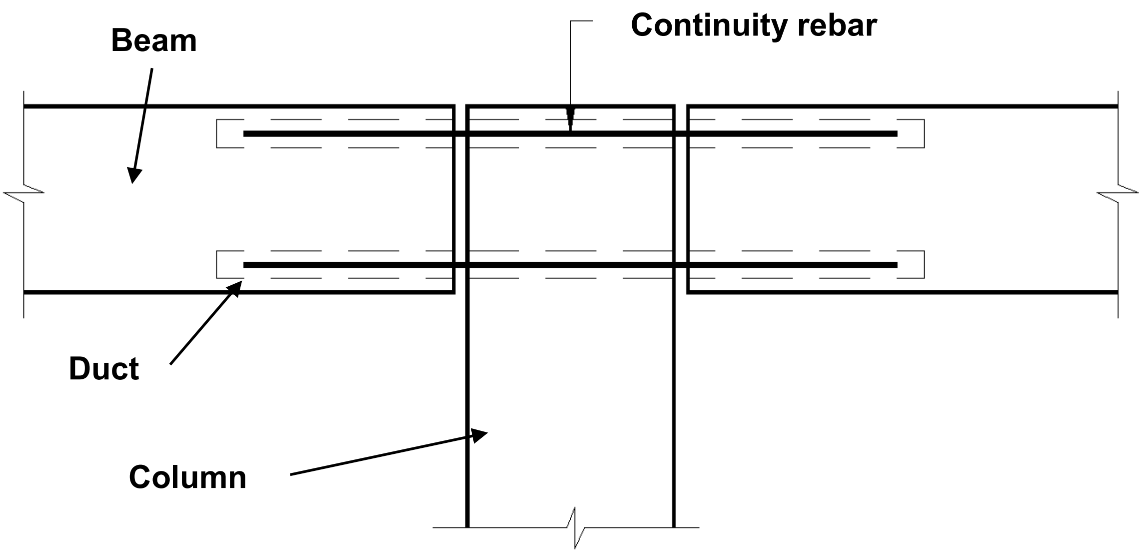


48B Corner Wall

FIG. 48 FLOOR SLAB TO WALL DETAILS

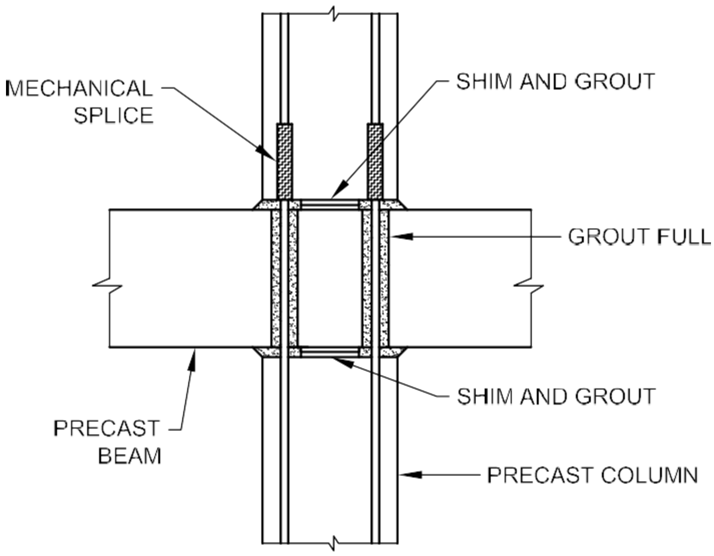


49A With CIS Joint



49B With Grouted Joint

FIG. 49 BEAM AND COLUMN



NOTE – Conduit diameter shoule be two to four times the bar diameter for tolerance in field erection

FIG. 50 COLUMN TO COLUMN THROUGH CONDUIT IN BEAM

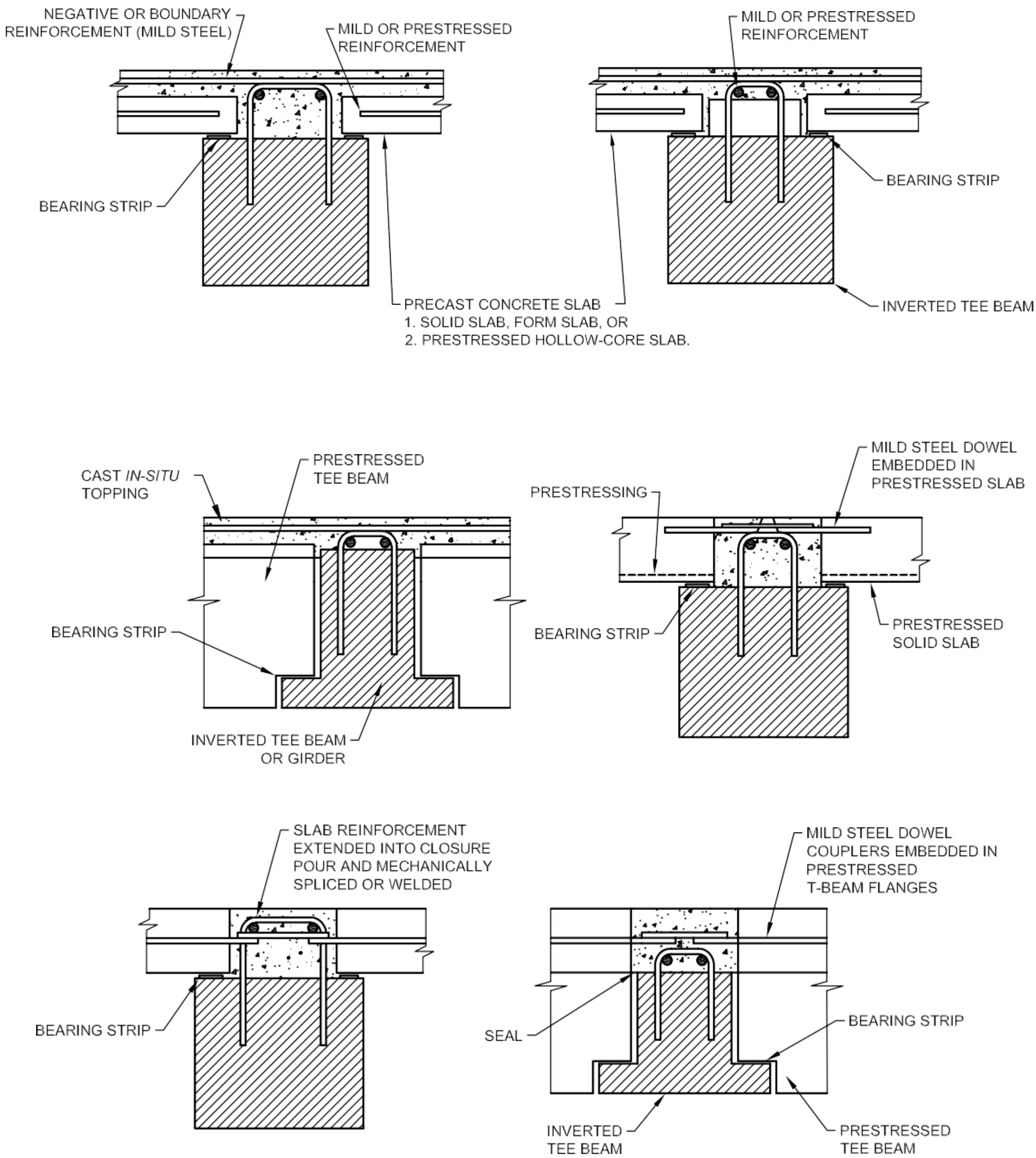


FIG. 51 TYPICAL CONNECTIONS OF PRECAST FLOOR SLAB ELEMENTS

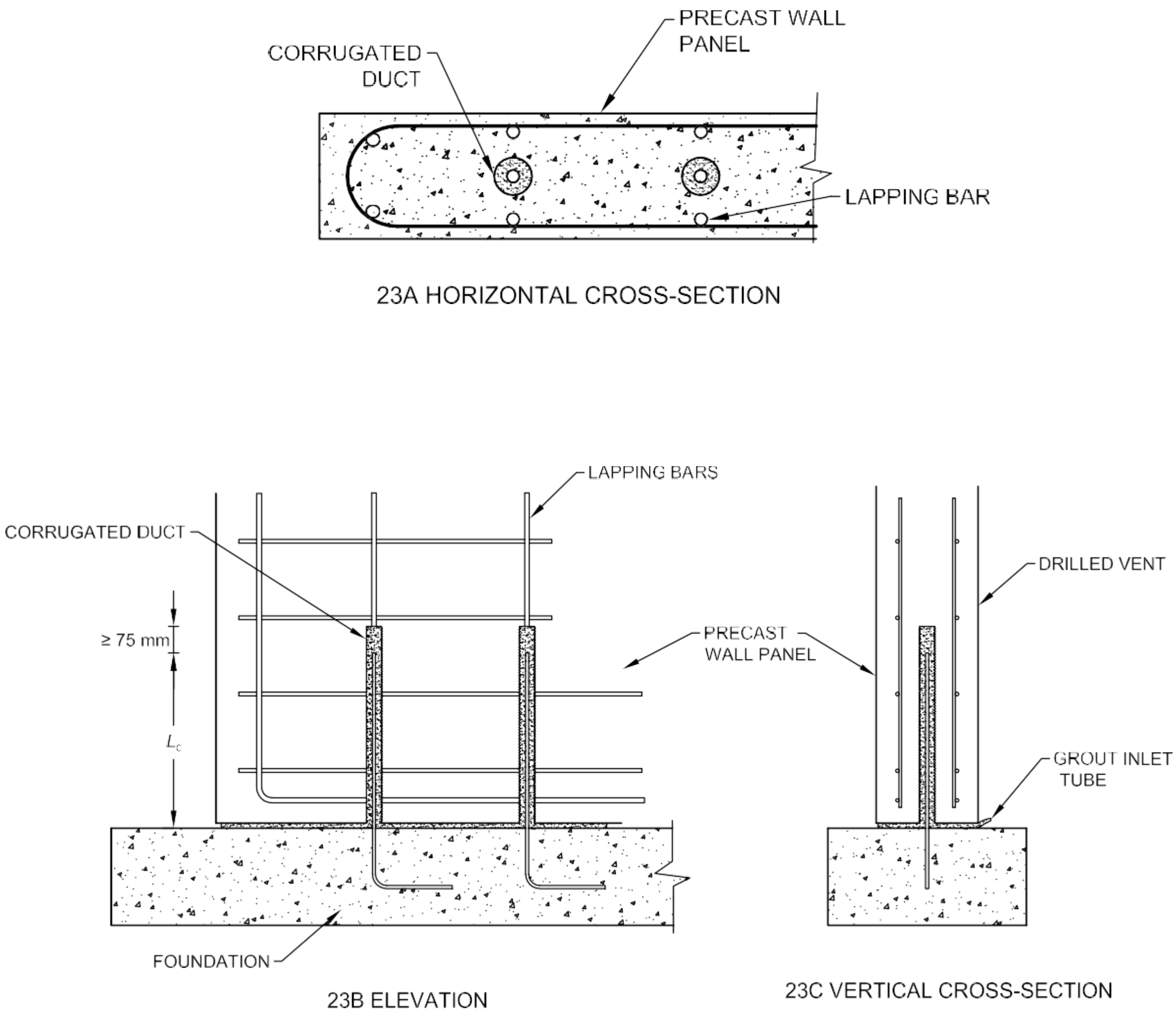


FIG. 52 WALL TO FOUNDATION CONNECTION THROUGH GROUTED DUCT

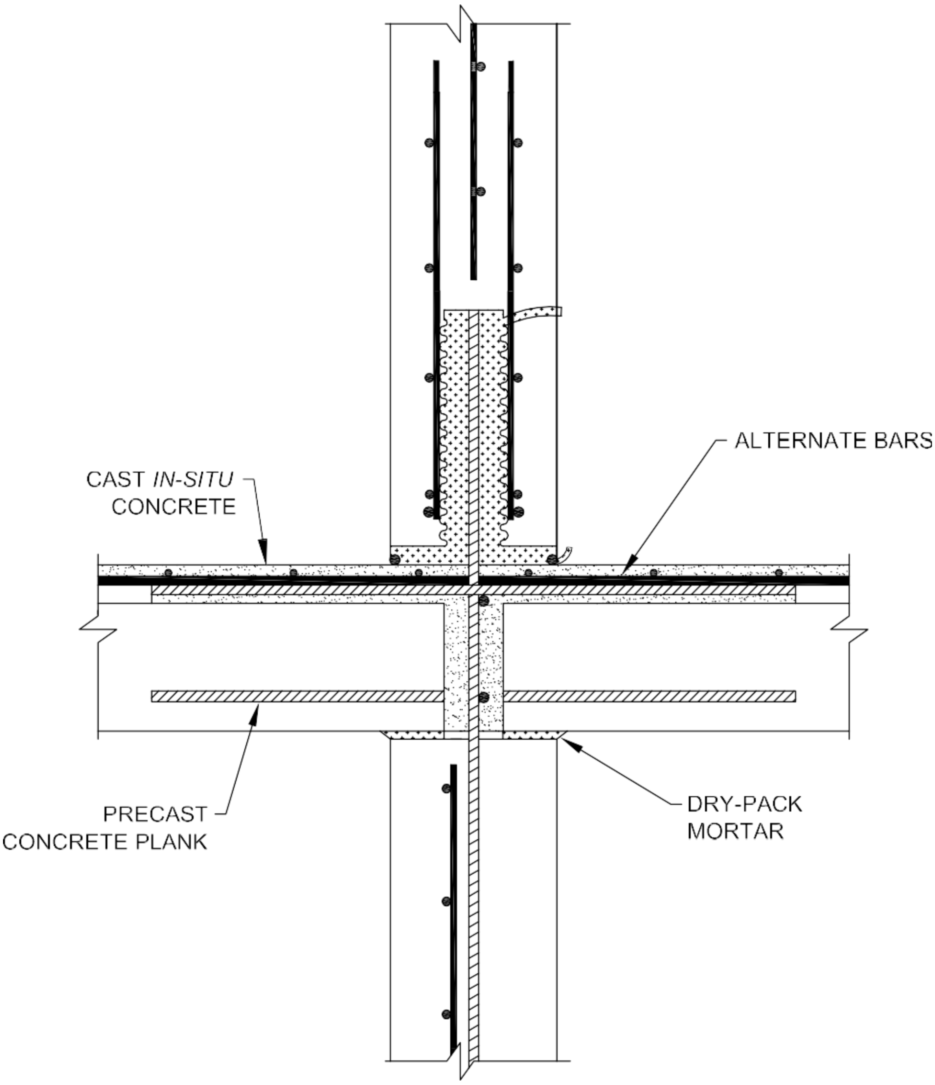


FIG. 53 WALL TO FLOOR SLAB CONNECTION

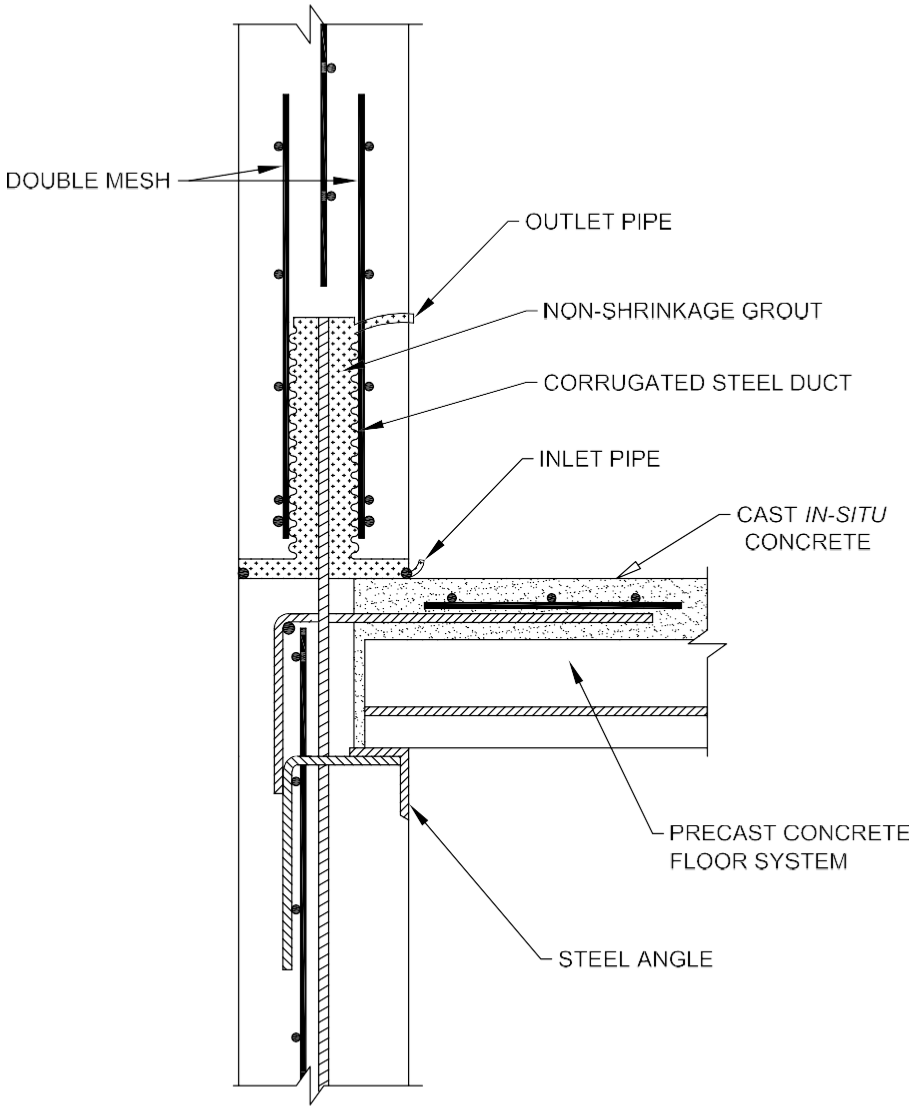


FIG. 54 EXTERIOR WALL TO FLOOR SLAB CONNECTION

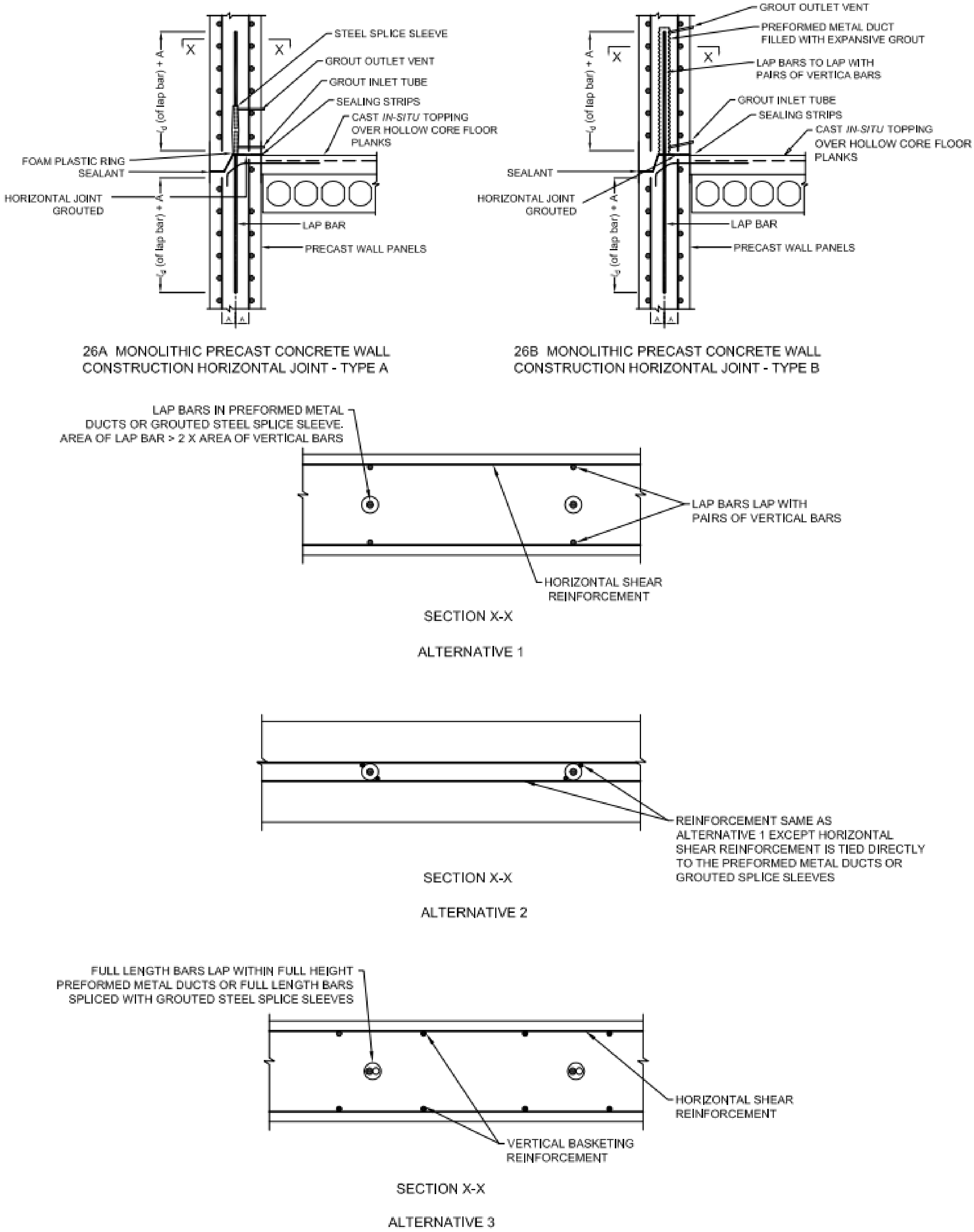


FIG. 55 MONOLITHIC PRECAST WALL CONSTRUCTION

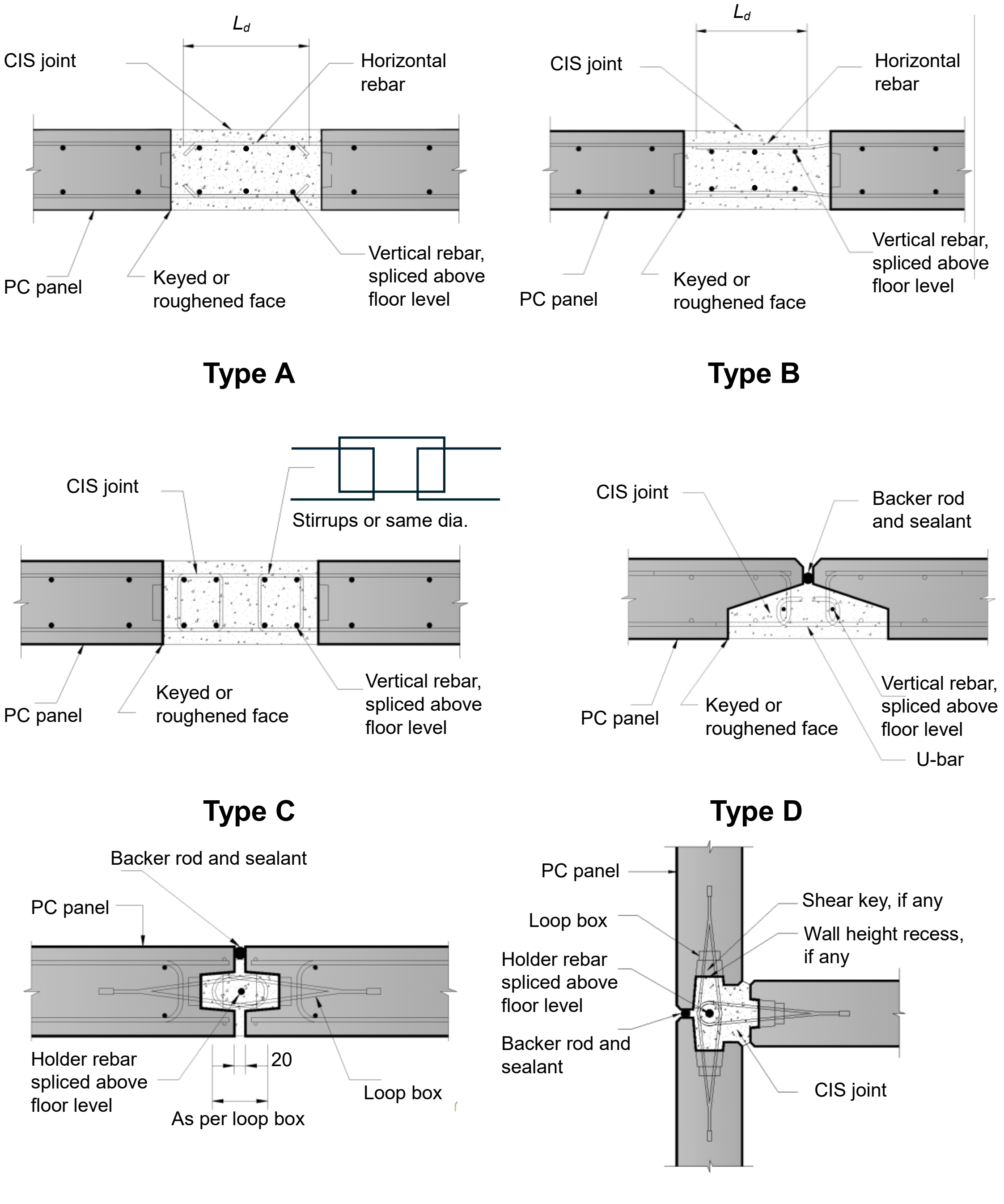
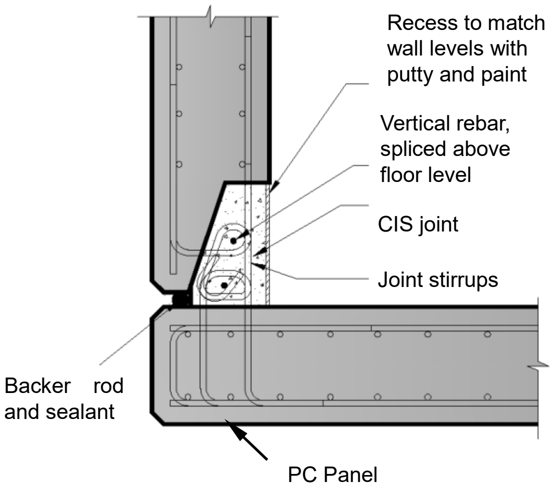
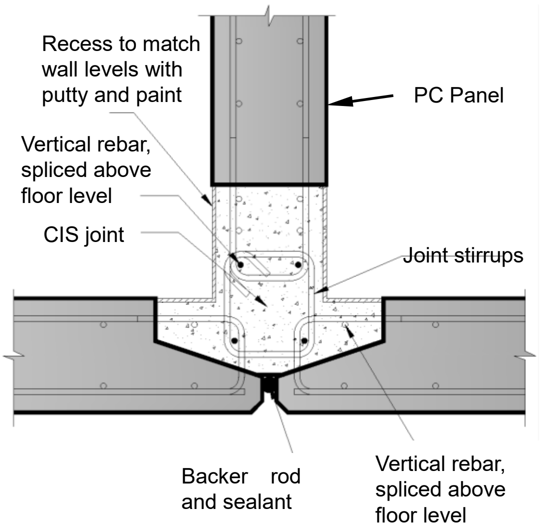


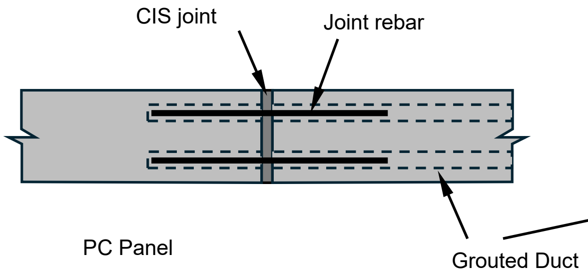
FIG. 56 VERTICAL JOINT BETWEEN WALL TO WALL OR WALL TO COLUMN (Contd.)



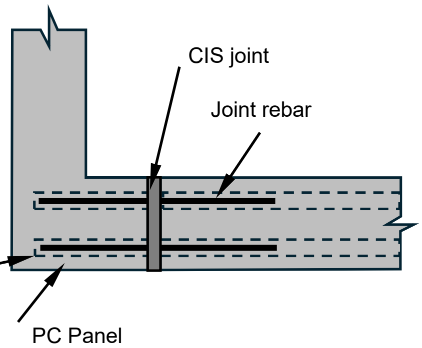
Type G



Type H



Type I



Type J

FIG. 56 VERTICAL JOINT BETWEEN WALL TO WALL OR WALL TO COLUMN

ANNEX E
(*Clause* 9)

COMMON DEFECTS AND REMEDIES

E-1 As defects in precast concrete elements result in direct and indirect cost in terms of rectification and construction time, it is worthwhile to ensure that they are produced and handled in a way to avoid/reduce such incidences. Table 18 illustrates some of these common defects, their causes and preventive measures.

Table 18 List of Common Defects and Recommended Measures
(*Clause* E-1)

SI No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
i)	Dimensional deviation: a) Variation in the dimension of precast elements would affect the joint alignment between these elements when erected b) Precast slab element may warp due to insufficient concrete strength at lifting or improper storage condition	a) Mould forms may not be sufficiently rigid to maintain specified tolerances during concrete placement b) Precast elements may not have gained sufficient concrete strength when demoulded c) Top surface finish of precast elements may not be properly levelled and trowelled during production which result in differential thickness d) Precast elements (especially slender wall or slab panels) may be subjected to undue stress and deformation when they are not properly supported during storage	a) Regular check on the dimensions and rigidity of mould forms before casting operations As a general guide the recommended thickness for steel mould are: 1) 4.5 mm – upto 50 castings, 2) 6 mm – upto 100 castings, and 3) 9 mm – upto 200 castings Mould forms conditions will deteriorate with time and usage. They should be repaired, stiffened or replaced when needed b) Cube tests should be conducted to ascertain the concrete strength of elements before demoulding c) Spreading and levelling of concrete placement using appropriate tools such as structural screeder d) Precast elements should be properly stored and stacked at designated points using suitable	a) For minor deviation, corrective measures such as surface grinding, trimming/ hacking and skim coat application can be appropriately used to remedy the situation. b) Precast elements that are not within acceptable tolerance limits and have significant effects on the structural integrity or architectural performance should not be used.

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
			support spacers and frame rack system	
ii)	Cracks	Precast elements may not have gained sufficient concrete strength before demoulding b) Cracks may have occurred during initial lifting due to friction between the elements and the casting mould forms c) Thickness of the precast elements may be too thin (70 mm or less) and flimsy for safe demoulding and handling d) Cracks may have occurred during erection due to lack of planning and provisions given to the precast panel geometry, crane rigging configuration and location of openings	a) Proper curing method, curing time and temperature should be maintained b) Cube tests should be conducted to ascertain the concrete strength of elements before demoulding c) Appropriate form release agents should be used and uniformly applied onto the mould surface to minimize friction d) Sectional thickness of precast elements should be increased to accommodate demoulding and handling stresses e) Proper handling techniques should be adopted f) Sufficient lifting points should be used to minimize over-stressing on certain areas g) Additional reinforcing bars should be placed around the opening and odd corners h) Temporary stiffeners for openings should be provided during erection	a) All cracks should be examined by a qualified engineer to determine if they present a structural problem. b) Depending on the locations and seriousness of the cracks, different repair methods can be used to make good the affected precast elements. c) Hairline cracks (not more than design crack width) can be repaired by cutting V-groove of specified minimum depth along the crack-lines, followed by patching subject to location and length of the crack in relation to length of units and not having adverse effect on the structural strength of the unit. For surface cracks (more than design crack width) or through cracks, epoxy injection method should be used to ensure that the cracks are completely bound and filled with epoxy.
iii)	Chip-off and damages	a) Chip-off at panel edges are usually caused by the hard	a) Precautions should be taken to avoid damaging the elements during placement on vehicle,	a) Remove all loose concrete and wash off any dust or dirt in the affected area.

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
		bearing at support or excessive force exerted on the elements when handling b) Improper storage method	travel to site and during the unloading operation. Bearing pads should be used to cushion the contact areas from damage b) The storage area should be relatively flat and dry c) Precast elements should be properly stored and stacked at designated points using suitable support spacers and frame rack system d) The casting slab or mould form should be thoroughly cleansed, levelled to achieve a smooth surface e) The coverage of form release agents should be adequate and uniformly applied onto the mould surface f) Spacers of the correct sizes should be used and well secured to maintain the concrete cover required during casting g) Lifting inserts and concrete strength of elements should be of adequate capacity for the intended lift. Use proprietary products for safe and efficient handling h) Lifting inserts or hooks should be inspected for proper location. They should be fastened	b) Apply bonding agent to affected concrete surface. c) Welded wire mesh can be included to provide support for the patch mix concrete or grout. d) Patch mix composition or grout should be consistent with the strength requirements of the adjacent concrete. e) Formwork is to be put up where it is necessary to contain the patch mix or grout. f) Protect the affected area from any disturbance during the curing period.

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
			to specified depth prior to concrete placement	
iv)	Honeycomb and excessive pinholes	a) Poor concrete compaction due to ineffective vibration or rebars congestion b) Grout leakage along the perimeter side forms due to: 1) Loose or missing bolts, fixing pins 2) Damaged rubber gasket seal 3) Mould part, if defective	a) Proper compaction methods should be adopted and carried out b) Concrete mix design and workability should be reviewed and adjusted when needed c) Appropriate concrete vibrator such as clamp-on form vibrator can be used to attain better compaction d) Rebar congestion can be alleviated by having larger (that is, lesser) rebars or by increasing the sectional dimensions of the elements where possible e) Mechanical couplers or sleeves can be used to simplify the reinforcement layout and to minimize rebar congestion f) Defective mould forms and accessories should be repaired or replaced to prevent grout leakage during concrete	a) Remove all loose concrete and wash off any dust or dirt in the affected area. b) Apply bonding agent to affected concrete surface. c) Welded wire mesh can be included to provide support for the patch mix concrete or grout. d) Patch mix composition or grout should be consistent with the strength requirements of the adjacent concrete. e) Formwork is to be put up where it is necessary to contain the patch mix or grout. f) Protect the affected area from any disturbance during the curing period.
v)	v) Missing or wrong details such as cast-in items, architectural nib and groove details, lifting hooks, reinforcement/starter bars/block-out/corrugated pipes	a) Items may not have been included in the shop drawing b) Quality checks may not be properly in place	a) All items should be reflected in the shop drawings for production. Any changes should be made known to the production team	a) Certain details such as missing starter bars/reinforcement and lifting hooks can be replaced by welding additional reinforcement bars after hacking

Sl No.	Common Defects	Possible Causes	Recommendations	Remedial Measures
(1)	(2)	(3)	(4)	(5)
			b) The use of checklists during inspection can help to ensure that all items specified in the drawing are included before casting	off the concrete at the affected area. b) Other items such as cast-in items, groove and block-out can be provided by chasing or chiselling out the face of the precast panels.
vi)	strand slippage which exceed allowable design values (item applicable to pre-stressed elements only) Slippages of pre-stressing strands can be detected by visual inspection	a) Insufficient bond strength between concrete and the pre-stressing strands b) Poor compaction of concrete around pre-stressed strands	a) Required concrete strength of the precast elements should be attained and verified by cube test results before de-tensioning of strands b) Proper compaction method should be adopted and carried out during casting c) Concrete mix design and workability should be reviewed and adjusted when needed d) Provision of appropriate concrete vibrator to attain better compaction	a) It is not possible to rectify the elements from strand slippage. b) Design verification should be carried out to ascertain the reduced capacity of the elements due to slippage, if adopted.
vi)	Alignment	Inaccurate setting out and positioning of precast elements during erection b) Deviation in the dimensions of the precast element	a) Appropriate surveying and levelling equipment should be used to achieve better alignment b) Required alignment and level should be confirmed before permanent jointing c) Critical dimensions of precast concrete elements should be verified before installation	a) Minor adjustments of the element/panel alignment can be done during installation However the effects on the final alignment and deviation of the building should be evaluated. b) For minor deviations, corrective measures such as surface grinding, trimming/

Sl No.	**Common Defects**	**Possible Causes**	**Recommendations**	**Remedial Measures**
(1)	(2)	(3)	(4)	(5)
				hacking and skim coat application can be appropriately used to rectify the precast elements before installation. c) Precast elements that are not within acceptable tolerance limits and have significant effects on the structural integrity or architectural performance should not be used.

ANNEX F
(*Clauses* 3, 5.1, 8.1.2, 8.9.9.1 *and* 9)

SUSTAINABILITY IN PRECAST CONCRETE CONSTRUCTION

F-1 GENERAL

This Annex presents sustainable practices in precast concrete construction, emphasizing methods for reducing environmental impacts, promoting resource conservation, and ensuring long-term viability. The discussion covers key sustainability factors, addressing the challenges and innovations that enable the industry to adopt greener and efficient solutions.

F-2 USE OF RECYCLED AGGREGATES IN PRECAST CONCRETE

F-2.1 Environmental Benefits

F-2.1.1 *Conservation of Natural Resources* – By reusing construction and demolition debris as recycled aggregates, the need for extracting virgin raw materials like sand and granite is significantly reduced, preserving ecosystems and minimizing environmental disruption.

F-2.1.2 *Reduction in Energy Use* – Recycled aggregates require less energy to process compared to natural aggregates, which leads to a lower carbon footprint during production. This also reduces the energy demand associated with quarrying, transportation, and processing.

F-2.1.3 *Circular Economy Impact* – Incorporating recycled aggregates into precast concrete non-structural components—such as paving slabs, curbs, and drainage systems, etc. supports a circular economy, minimizing waste sent to landfills and promoting the reuse of construction materials.

F-2.2 Challenges and Innovations

F-2.2.1 *Ensuring Consistent Quality* – Recycled aggregates may exhibit variability in size and composition, potentially impacting concrete strength and durability. Innovations in sorting, crushing, and refining technologies can improve the consistency and reliability of recycled aggregates.

F-2.2.2 *Efficient Use of Water* – In general, excessive water is required to be used while using recycled aggregate and can have negative environmental impacts. By adopting optimized mix designs and water-efficient technologies, the water demand for concrete production can be significantly reduced.

F-2.2.3 *Advancement in Sustainable Mixes* – New research into mix designs is focusing on achieving better integration of recycled aggregates without compromising the material’s strength or durability. This can lead to a more sustainable, high-performance concrete product.

F-3 ADOPTION OF RENEWABLE ENERGY SOURCES

F-3.1 Environmental Benefits

F-3.1.1 *Decarbonizing Operations* – Shifting precast concrete manufacturing facilities to renewable energy sources, such as solar, wind, and hydropower, significantly reduces reliance on fossil fuels, helping to lower overall greenhouse gas emissions and mitigate climate change impacts.

F-3.1.2 *Electric and Hybrid Machinery* – By replacing conventional diesel-powered equipment with electric and hybrid alternatives, the precast concrete industry can reduce air pollution and carbon emissions associated with construction machinery.

F-3.2 Challenges and Innovations

F-3.2.1 *High Initial Costs* – The transition to renewable energy systems and low-emission machinery involves substantial initial investment. However, long-term operational savings, combined with available financial incentives for green technologies, can help offset the upfront costs.

F-3.2.2 *Energy Storage and Smart Grids* – Installing energy storage solutions, such as batteries, in conjunction with on-site renewable energy systems can help mitigate energy supply issues during periods of high demand or when renewable energy generation is low, further reducing dependence on the traditional energy grid.

F-4 REDUCING SITE POLLUTION AND WASTE

F-4.1 Environmental Benefits

F-4.1.1 *Waste Minimization* – Precast construction reduces on-site waste generation because most components are manufactured off-site in controlled factory settings. This reduces waste sent to landfills and minimizes the potential for soil and water contamination and helps in achieving undisturbed site.

F-4.1.2 *Reduced Emissions and Noise Pollution* – Precast methods reduce the need for heavy on-site machinery and long construction timelines. As a result, there is less air pollution, noise pollution, and disturbance to nearby ecosystems or communities.

F-4.2 Challenges and Innovations:

F-4.2.1 *Reducing Transportation Emissions* – Transporting precast components to construction sites can contribute to emissions, especially when distances are long. This can be minimized by optimizing transportation logistics, using hybrid or electric vehicles, and focusing on the use of modular components that reduce transportation needs.

F-4.2.2 *On-Site Pollution Prevention* – During installation, on-site pollution—such as dust or runoff—can still occur. Simple practices like water misting to suppress dust and covering concrete surfaces to prevent runoff can significantly reduce the environmental impact of installation activities.

F-5 USE OF SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs) AND OPTIMIZED CONCRETE MIXES

F-5.1 Environmental Benefits

F-5.1.1 *Low-Carbon Alternatives to Cement* – Replacing traditional Portland cement with supplementary cementitious materials (SCMs) such as fly ash, slag, or natural pozzolans can drastically reduce the carbon footprint of concrete production by minimizing the need for energy-intensive cement manufacturing.

F-5.1.2 *Efficient Resource Use* – Advanced mix designs, including high-performance concrete (HPC) and ultra-high-performance concrete (UHPC), allow for the reduction of material consumption without sacrificing strength or durability. These innovations help to optimize the use of raw materials, ensuring sustainability in production.

F-5.2 Challenges and Innovations

F-5.2.1 *Durability and Performance* – While reducing cement content or using alternative binders can lower the carbon footprint, it is essential to ensure the long-term durability and performance of the concrete. Research into material science continues to improve the durability of low-carbon and alternative binder concrete options.

F-5.2.2 *Geopolymer Concrete* – Geopolymer concrete, made from industrial by-products has a lower carbon footprint compared to traditional cement-based concrete and can be used in precast applications without compromising strength and durability.

F-6 SUSTAINABLE DESIGN AND PRODUCTION OPTIMISATION

F-6.1 Environmental Benefits

F-6.1.1 *Material Efficiency through Design* – Precast elements can be optimised for material efficiency by carrying out optimum design. BIM allows for detailed digital models that reduce waste during both the design and construction phases.

F-6.1.2 *Modular and Prefabricated Systems* – The use of modular designs with standardization in precast construction can reduce material waste, reducing production time, reuse of mould and optimize the process of precasting.

F-6.2 Challenges and Innovations

F-6.2.1 *Customization vs. Standardization* – While standardisation helps reduce waste and increase efficiency, some projects require customised solutions. The challenge lies in finding a balance between benefits of standardised components and the need for bespoke, project-specific designs.

F-6.2.2 *3D Printing and Additive Manufacturing* – Emerging technologies like 3D printing could revolutionise precast construction (refer Annex A). By using digital fabrication techniques, custom shapes and optimized designs can be produced efficiently, with less material wastage.

F-7 TRANSPARENCY, CERTIFICATION, AND ETHICAL PRACTICES

F-7.1 Sustainability Governance

F-7.1.1 *Environmental Certifications* – Precast manufacturers and construction companies can pursue certifications such as Environmental Management Systems, LEED, or IGBC to demonstrate their commitment towards achieving sustainability. These certifications set a global benchmark for eco-friendly practices in construction.

F-7.1.2 *Ethical Sourcing and Labour Practices* – Sustainable construction practices require ethical sourcing of materials, ensuring that raw materials are extracted responsibly, and workers are treated fairly. This also includes adherence to international labour standards and human rights protections.

F-7.2 Challenges and Innovations

F-7.2.1 *Data Transparency* – As consumer and regulatory demand for sustainability data increases, companies are under pressure to disclose their environmental impacts. Technologies like block-chain offer innovative solutions for ensuring transparency and accountability in reporting environmental performance.

F-7.2.2 *Community and Stakeholder Engagement* – Actively engaging with local communities, government bodies, and customers to ensure that sustainability goals align with the social expectations and needs of stakeholders.

LIST OF STANDARDS

The following list records those standards which are acceptable as 'good practice' and 'accepted standards' in the fulfilment of the requirements of the Code. The latest version of a standard shall be adopted at the time of enforcement of the Code. The standards listed may be used by the Authority as a guide in conformance with the requirements of the referred clauses in the Code.

In the following list, the number appearing in the first column within parentheses indicates the number of the reference in this Part/Section.

	IS No.	*IS Title*
(1)	13920 : 2016	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (f*irst revision*)
(2)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	1343 : 2012	Prestressed Concrete - Code of Practice (*second revision*)
(3)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
(4)	383 : 2016	Coarse and Fine Aggregate for Concrete - Specification (third revision)
	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
(5)	9103 : 1999	Concrete Admixtures -Specification (*first revision*)
	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
(6)	10262 : 2019	Concrete Mix Proportioning — Guidelines (*second revision*)
	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
(7)	1199 : 1959	Methods of sampling and analysis of concrete
(8)	10262 : 2019	Concrete Mix Proportioning — Guidelines (*second revision*)
	1199 : 1959	Methods of sampling and analysis of concrete
(9)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	9417 : 2018	Welding of High Strength Steel Bars for Reinforced Concrete Construction - Recommendations (*second revision*)
(10)	16172 : 2023	Reinforcement Couplers for Mechanical Splices of Steel Bars in Concrete - Specification (*first revision*)
(11)	18256 : 2023	Solid Round Glass Fibre Reinforced Polymer (GFRP) Bars for Concrete Reinforcement - Specification
(12)	1566 : 1982	Specification for Hard-Drawn Steel Wire Fabric for Concrete Reinforcement (*second revision*)
(13)	1343 : 2012	Prestressed Concrete - Code of Practice (*second revision*)

	IS No.	*IS Title*
(14)	14343 : 1996	Choice of grouting, materials for alluvial grouting - Guidelines
(15)	4671 : 2018	Expanded polystyrene for thermal insulation purposes - Specification
(16)	8183 : 2024	Bonded mineral wool - Specification
(17)	6598 : 2018	Cellular concrete for thermal insulation - Specification (f*irst revision*)
(18)	10297 : 1982	Code of practice for design and construction of floors and roofs using precast reinforced/prestressed concrete ribbed or cored slab units
(19)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	1893 (Part 1) : 2016	Criteria for Earthquake Resistant Design of Structures - Part 1 - General Provisions and Buildings (*sixth revision*)
	13920 : 2016	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (f*irst revision*)
(20)	16700 : 2023	Criteria for Structural Safety of Tall Concrete Buildings (*first revision*)
(21)	875 (Part 1) : 1987 (Part 2) : 1987 (Part 3) : 2015 (Part 4) : 2021 (Part 5) : 1987	Code of practice for design loads (Other Than Earthquake) for buildings and structures Part 1 dead loads - Unit weights of building materials and stored materials (*second revision*) Part 2 imposed loads (*second revision*) Part 3 Wind Loads (*third revision*) Part 4 Snow Loads (*third revision*) Part 5 special loads and load combinations (*second revision*)
(22)	875 (Part 1) : 1987	Code of practice for design loads (Other Than Earthquake) for buildings and structures: Part 1 dead loads - Unit weights of building materials and stored materials (*second revision*)
(23)	875 (Part 2) : 1987	Code of practice for design loads (Other Than Earthquake) for buildings and structures: Part 2 imposed loads (*second revision*)
(24)	875 (Part 3) : 2015	Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice Part 3 Wind Loads (*third revision*)
(25)	1893 : 1984	Criteria for Earthquake Resistant Design of Structures (*fourth revision*)
(26)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	1893 : 1984	Criteria for Earthquake Resistant Design of Structures (*fourth revision*)

	IS No.	*IS Title*
(27)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	1893 : 1984	Criteria for Earthquake Resistant Design of Structures (*fourth revision*)
	800 : 2007	General construction in steel - Code of practice (*third revision*)
(28)	1641 : 2013	Fire safety of buildings (General) - General principles of fire grading and classification - Code of practice (*second revision*)
(29)	1642 : 2013	Fire safety of buildings (General) - Details of construction - Code of practice (*second revision*)
(30)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	13920 : 2016	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (f*irst revision*)
(31)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	1343 : 2012	Prestressed Concrete - Code of Practice (*second revision*)
	13920 : 2016	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (f*irst revision*)
(32)	1893 : 1984	Criteria for Earthquake Resistant Design of Structures (*fourth revision*)
	16700 : 2023	Criteria for Structural Safety of Tall Concrete Buildings (*first revision*)
(33)	800 : 2007	General construction in steel - Code of practice (*third revision*)
(34)	4082 : 1996	Stacking and storage of construction materials and components at site - Recommendations (s*econd revision*)
(35)	1893 (Part 1) : 2016	Criteria for Earthquake Resistant Design of Structures - Part 1 - General Provisions and Buildings (*sixth revision*)
	4326 : 2013	Earthquake resistant design and construction of buildings - Code of practice
	13920 : 2016	Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (f*irst revision*)
(36)	1641 : 2013	Fire safety of buildings (General) - General principles of fire grading and classification - Code of practice (*second revision*)
	1642 : 2013	Fire safety of buildings (General) - Details of construction - Code of practice (*second revision*)
	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)

	IS No.	*IS Title*
	800 : 2007	General construction in steel - Code of practice (*third revision*)
(37)	3935 : 1966	Code of practice for composite construction
(38)	3201 : 1988	Criteria for Design and Construction of Precast Concrete Trusses and Purlins (*first revision*)
(39)	6332 : 1984	Code of practice for construction of floor and roofs using precast doubly-curved shell units
	10297 : 1982	Code of practice for design and construction of floors and roofs using precast reinforced/prestressed concrete ribbed or cored slab units
	10505 : 1983	Code of practice for construction of floors and roofs using precast concrete waffle units
	13994 : 1994	Design and Construction of Floor and Roof with Precast Reinforced Concrete Planks and Joists - Code of Practice
	14142 : 1994	Design and construction of floors and roofs with prefabricated brick panel - Code of practice
	14215 : 1994	Design and construction of floors and roofs with precast reinforced concrete channel units - Code of practice
	14242 : 1995	Design and construction of roofs using precast reinforced concrete L - Panels - Code of practice
(40)	11447 : 1985	Code of practice for construction with large panel prefabricates
(41)	6061 (Part 1) : 1971 (Part 2) : 1981 (Part 3) : 1981 (Part 4) : 1981	Code of practice for construction of floor and roof with joists and filler blocks Part 1 with hollow concrete filler blocks Part 2 with hollow clay filler blocks (*first revision*) Part 3 with precast hollow clay block joists and hollow clay filler blocks Part 4 with precast hollow clay block slab panels
(42)	4905 : 2015 ISO 24153 : 2009	Random sampling and randomization procedures (*first revision*)
(43)	14687 : 1999	Falsework for Concrete Structures - Guidelines
(44)	2185 (Part 1) : 2005	Concrete masonry units - Specification: Part 1 hollow and solid concrete blocks (*third revision*)
(45)	3952 : 2013	Burnt clay hollow bricks for walls and partitions - Specification
(46)	2185 (Part 3) : 1984	Specification for Concrete Masonry Units Part 3 Autoclaved Cellular (Aerated) Concrete Blocks (*first revision*)
(47)	1905 : 1987	Structural use of unreinforced masonry - Code of practice (*third revision*)
(48)	15916 : 2020	Building Design and Erection Using Prefabricated Concrete - Code of Practice (*first revision*)

	IS No.	*IS Title*
(49)	4101 (Part 2) : 1967	Code of practice for external facings and veneers - Part 2 Cement concrete facing
(50)	1950 : 1962	Code of practice for sound insulation of non-industrial buildings
(51)	3483 : 1965	Code of Practice for Noise Reduction in Industrial Buildings
	2526 : 1963	Code of practice for acoustical design of auditoriums and conference halls
(52)	1904 : 2021	General requirements for design and construction of foundations in soils — Code of practice (*fourth revision*)
(53)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	15916 : 2020	Building Design and Erection Using Prefabricated Concrete - Code of Practice (*first revision*)
(54)	516 (Part 1/Sec 1) : 2021	Hardened concrete - Methods of test: Part 1 Testing of strength of hardened concrete: Section 1 Compressive, flexural and split tensile strength (*first revision*)
(55)	1893 : 1984	Criteria for Earthquake Resistant Design of Structures (*fourth revision*)
	3414 : 1968	Code of Practice for Design and Installation of Joints in Buildings
(56)	456 : 2000	Plain and reinforced concrete - Code of practice (*fourth revision*)
	800 : 2007	General construction in steel - Code of practice (*third revision*)
(57)	1786 : 2008	High Strength Deformed Steel Bars and Wires for Concrete Reinforcement - Specification (f*ourth revision*)
(58)	383 : 2016	Coarse and Fine Aggregate for Concrete - Specification (third revision)
(59)	SP 30 : 2023	National Electrical Code of India 2023 (*second revision*)
	732 : 2019	Code of practice for electrical wiring installations (*fourth revision*)
(60)	62305 (Part 1) : 2010	Protection against lightning - Part 1 general principles
(61)	2065 : 1983	Code of practice for water supply in buildings (*second revision*)
	1742 : 1983	Code of practice for building drainage (*second revision*)
(62)	1742 : 1983	Code of practice for building drainage (*second revision*)
	12183 (Part 1) : 1987	Code of Practice for Plumbing in Multi-storeyed Buildings - Part 1 Water Supply

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