PRECAST STRUCTURES

DESIGN CONSIDERATIONS IN SEISMIC ZONES

AGENDA

- PRECAST STRUCTURE DEFINITION
- EMULATIVE DESIGN
- NON-EMULATIVE DESIGN
- EMULATED CONVERSION EXAMPLE
- CONCERNS RAISED IN THE PHILIPPINES

PRECAST STRUCTURE DEFINITION

- A REINFORCED CONCRETE STRUCTURE NOT FORMED IN PLACE WHERE PRECAST COMPONENTS SUPPORT GRAVITY LOADS AND/OR RESIST LATERAL LOADS

PRECAST ELEMENT DEFINITION

- A REINFORCED CONCRETE MEMBER NOT FORMED IN PLACE PRODUCED IN A PLANT OR ON SITE LIFTED INTO PLACE

WHAT TYPE OF STRUCTURES

- PRECAST IS USED IN ALL TYPES OF STRUCTURES

PRECAST CHARACHTERISTICS

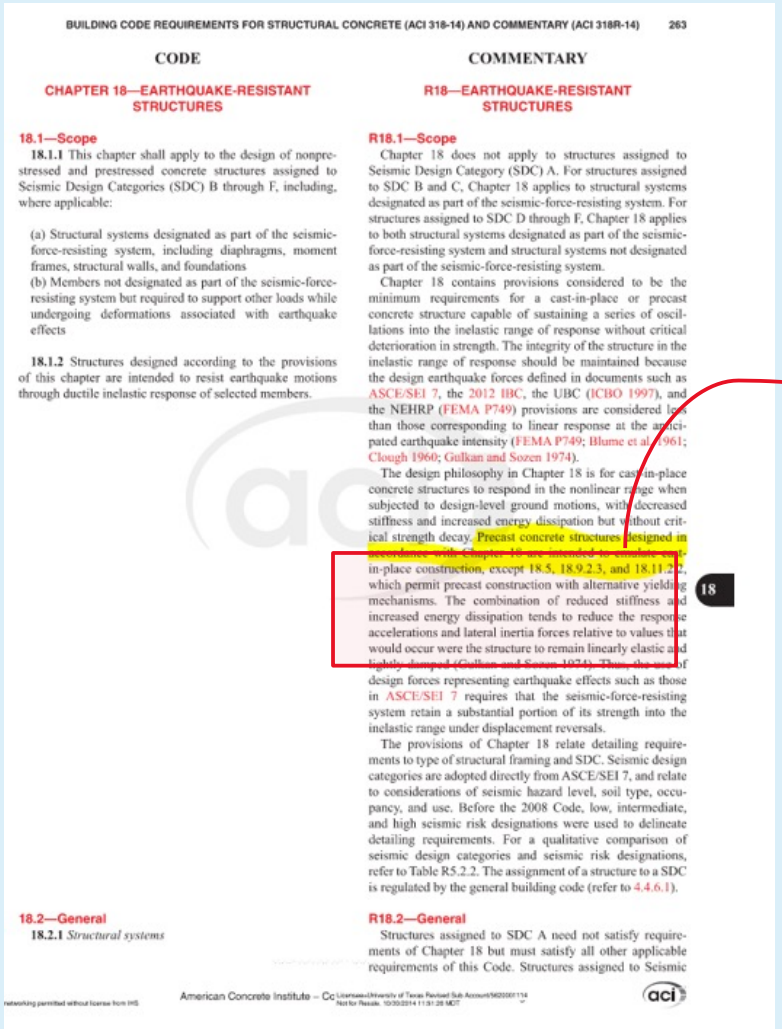
- QUALITY PRODUCTS
- FAST CONSTRUCTION
- LONGER SPAN
- REDUCED LABOR
- ENVIRONMENTALLY FRIENDLY
- VERSATILE

HOW DO YOU DESIGN A PRECAST STRUCTURE?

- CONVERT FROM IN-SITU TO PRECAST – EMULATIVE DESIGN
- PRECAST DESIGN NON EMULATIVE

EMULATIVE DESIGN

- GOVERNING CODE ACI-318 18.1.2 ALLOWS EMULATIVE DESIGN



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CODE

CHAPTER 18—EARTHQUAKE-RESISTANT STRUCTURES

18.1—Scope

18.1.1 This chapter shall apply to the design of nonprestressed and prestressed concrete structures assigned to Seismic Design Categories (SDC) B through F, including, where applicable:

(a) Structural systems designated as part of the seismic-force-resisting system, including diaphragms, moment frames, structural walls, and foundations
(b) Members not designated as part of the seismic-force-resisting system but required to support other loads while undergoing deformations associated with earthquake effects

18.1.2 Structures designed according to the provisions of this chapter are intended to resist earthquake motions through ductile inelastic response of selected members.

18.2—General

18.2.1 *Structural systems*

COMMENTARY

R18—EARTHQUAKE-RESISTANT STRUCTURES

R18.1—Scope

Chapter 18 does not apply to structures assigned to Seismic Design Category (SDC) A. For structures assigned to SDC B and C, Chapter 18 applies to structural systems designated as part of the seismic-force-resisting system. For structures assigned to SDC D through F, Chapter 18 applies to both structural systems designated as part of the seismic-force-resisting system and structural systems not designated as part of the seismic-force-resisting system.

Chapter 18 contains provisions considered to be the minimum requirements for a cast-in-place or precast concrete structure capable of sustaining a series of oscillations into the inelastic range of response without critical deterioration in strength. The integrity of the structure in the inelastic range of response should be maintained because the design earthquake forces defined in documents such as ASCE/SEI 7, the 2012 IBC, the UBC (ICBO 1997), and the NEHRP (FEMA P749) provisions are considered less than those corresponding to linear response at the anticipated earthquake intensity (FEMA P749; Blume et al. 1961; Clough 1960; Gulkan and Sozen 1974).

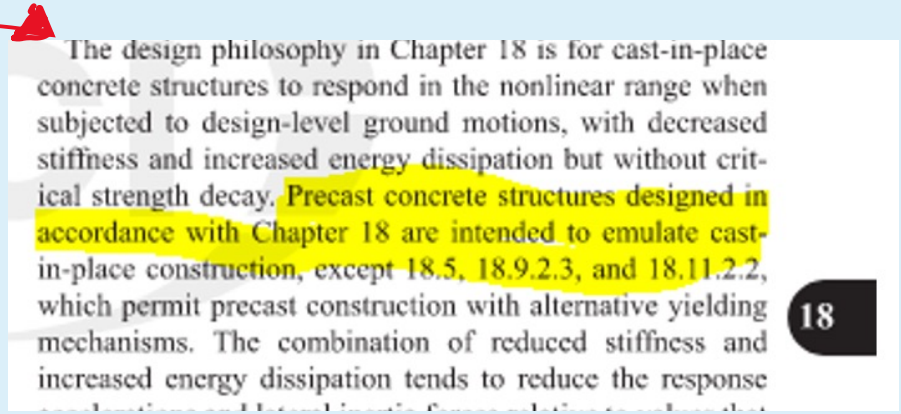
The design philosophy in Chapter 18 is for cast-in-place concrete structures to respond in the nonlinear range when subjected to design-level ground motions, with decreased stiffness and increased energy dissipation but without critical strength decay. Precast concrete structures designed in accordance with Chapter 18 are intended to emulate cast-in-place construction, except 18.5, 18.9.2.3, and 18.11.2.2, which permit precast construction with alternative yielding mechanisms. The combination of reduced stiffness and increased energy dissipation tends to reduce the response accelerations and lateral inertia forces relative to values that would occur were the structure to remain linearly elastic and lightly damped (Gulkan and Sozen 1974). Thus, the use of design forces representing earthquake effects such as those in ASCE/SEI 7 requires that the seismic-force-resisting system retain a substantial portion of its strength into the inelastic range under displacement reversals.

The provisions of Chapter 18 relate detailing requirements to type of structural framing and SDC. Seismic design categories are adopted directly from ASCE/SEI 7, and relate to considerations of seismic hazard level, soil type, occupancy, and use. Before the 2008 Code, low, intermediate, and high seismic risk designations were used to delineate detailing requirements. For a qualitative comparison of seismic design categories and seismic risk designations, refer to Table R5.2.2. The assignment of a structure to a SDC is regulated by the general building code (refer to 4.4.6.1).

R18.2—General

Structures assigned to SDC A need not satisfy requirements of Chapter 18 but must satisfy all other applicable requirements of this Code. Structures assigned to Seismic

18



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18

EMULATIVE DESIGN

- ACI-550 REFERENCED BY ACI-318 ALLOWS REINFORCING TYPE 2 SPLICES ANYWHERE

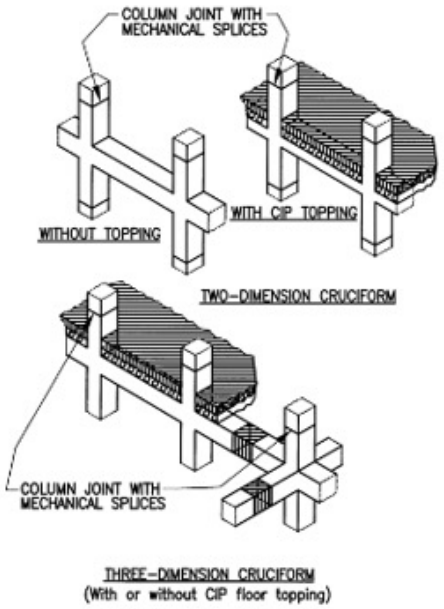


Fig. 7—Typical types of precast concrete "cruciform" elements.

For shear-wall structures, highway bridge-clearance gener-
ally restricts panel dimensions. Clearance limitations usually
restrict box module heights to approximately one building sto-

tended precast concrete manufacturer before proceeding with the design.

CHAPTER 4—CONNECTION OF PRECAST ELEMENTS

Methods to field-connect precast concrete elements should optimize the safety and efficiency of crane and erection crew operations. Because the unit cost of crane time and erection crew time is relatively high, erection scheduling and field connections that use the least amount of time in field assembly can be quite cost-effective. Where ductility is needed, the key element in achieving successful emulation is in selecting field connection details.

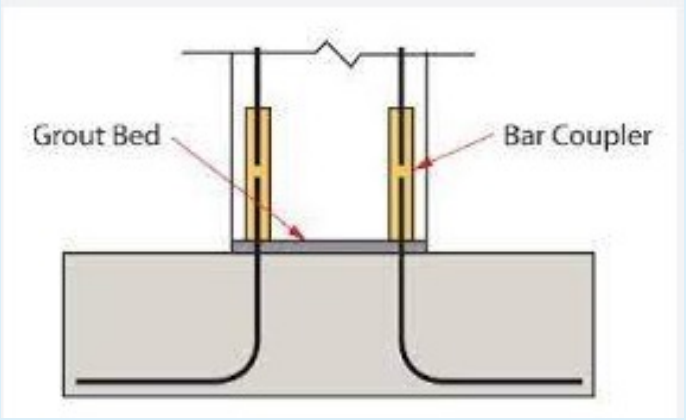
Splices for reinforcement used with precast systems that emulate monolithic cast-in-place systems generally involve lapped bars, mechanical splices, and welded splices. When lapped bars are used, the laps need to extend for significant lengths of cast-in-place concrete to permit the lap lengths and confinement hoops required by ACI 318-99, Chapter 21. The cast-in-place section will have to be as long as the required splice length for the bars. In ACI 318-99, mechanical splices are divided into two classifications: Type 1 and Type 2. These mechanical splices are those that meet the requirements of ACI 318-99, Section 12.14.3.2. These splices cannot be used within a distance of two times the member depth from the column or beam face or from sections where reinforcement yielding is anticipated. Type 2 mechanical splices have to develop the specified strength of the spliced bar. The specific requirements for these splices are discussed as follows. Type 2 splices are permitted at any location within a structural element. Welded splices are limited in use similar to Type 1 splices.

4.1—Connections in wall systems

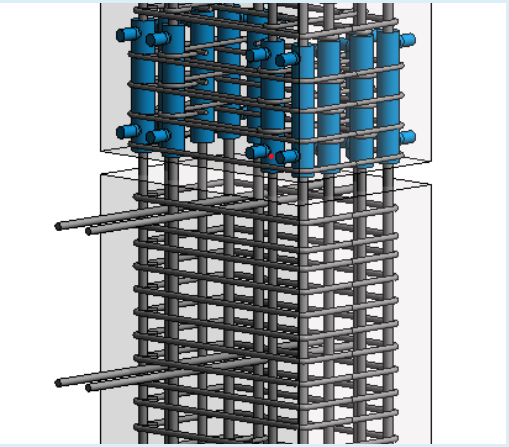
ing is anticipated. Type 2 mechanical splices have to develop the specified strength of the spliced bar. The specific requirements for these splices are discussed as follows. Type 2 splices are permitted at any location within a structural element. Welded splices are limited in use similar to Type 1 splices.

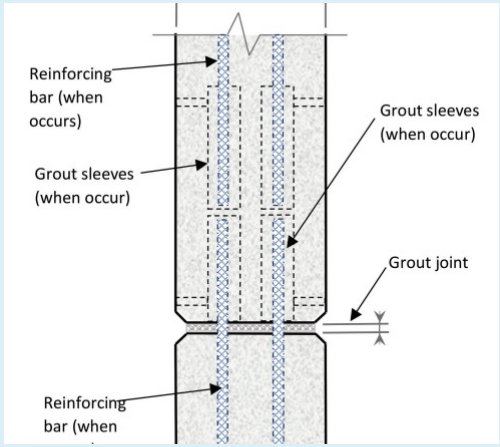
EMULATED STRUCTURE

- A PRECAST STRUCTURE WHERE ANY REINFORCING CROSSING A JOINT MUST BE TYPE 2 SPLICING AND DEEMED TO BE EQUIVALENT OR BETTER THAN A MONOLITHIC IN-SITU CONSTRUCTION BY TEST.



PRECAST TO IN-SITU

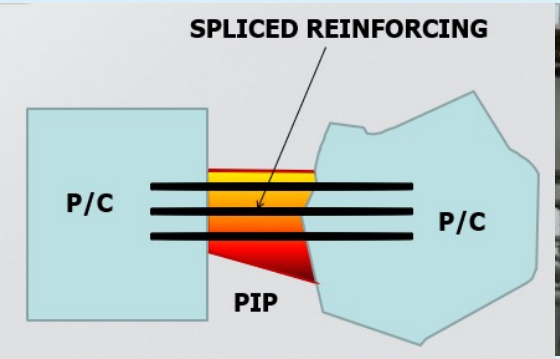




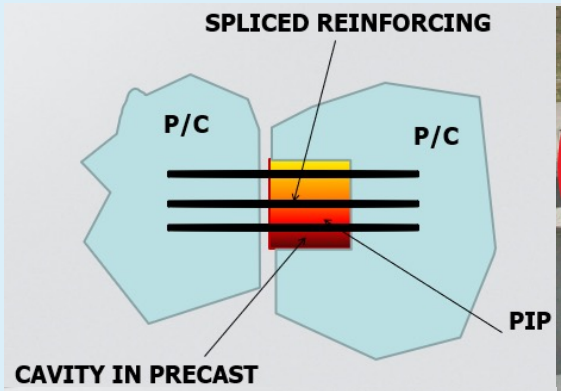
PRECAST TO PRECAST - VERTICAL

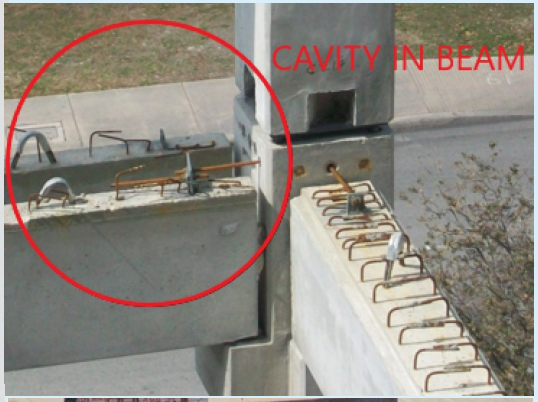
PRECAST TO PRECAST - HORIZONTAL

TYPE OF CONNECTIONS

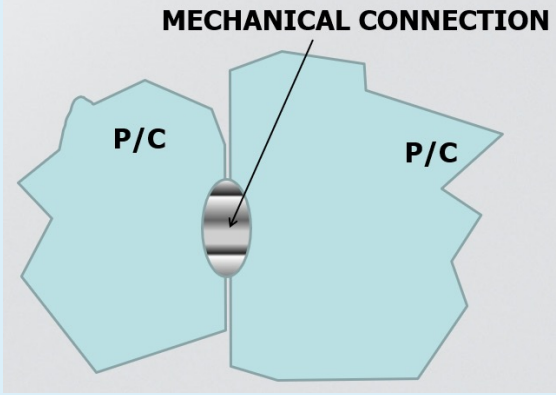


WET JOINT





SEMI DRY JOINT

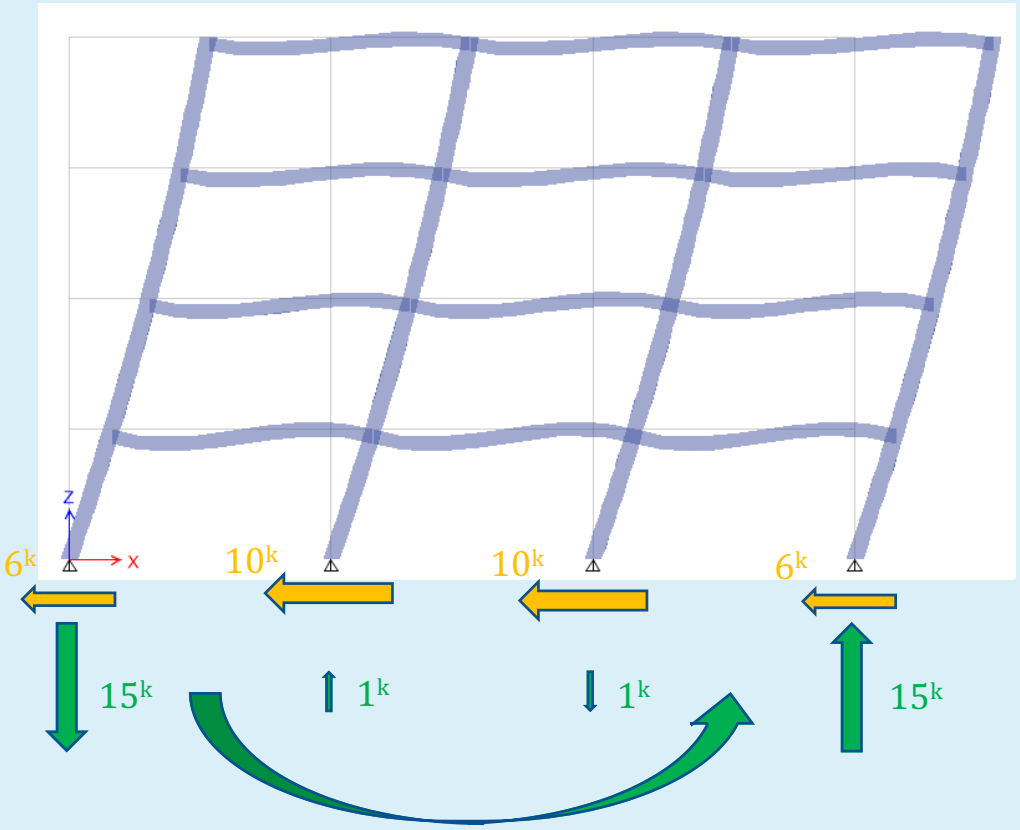


DRY JOINT

ASPECTS OF EMULATIVE DESIGN

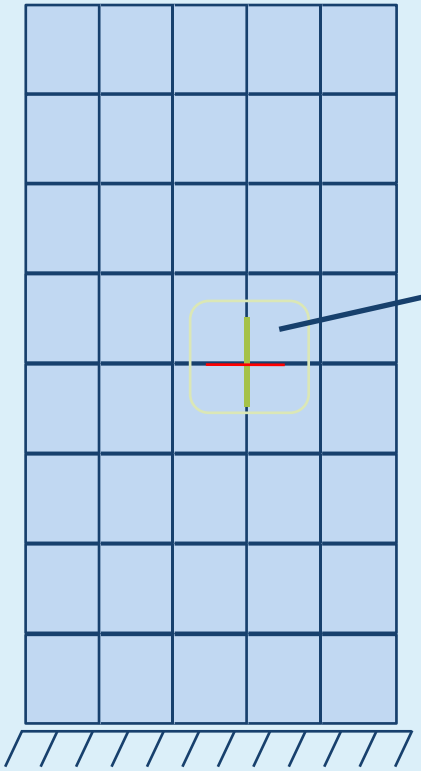
- **PRECAST TO PRECAST AND PRECAST TO PIP ARE JOINTED CONNECTIONS**
  - INTEGRITY REINFORCING NEEDS NOT SPLICING
  - FORCES MUST BE TRANSFERRED ACROSS THE JOINT
  - SHEAR FRICTION FOR SHEAR TRANSFER IS ALLOWED
  - SYSTEM DEFORMATION MUST BE WITHIN 80% OF PIP SYSTEM
  - JOINT MUST BE GROUTED WITH MAX. STRENGTH OF CONNECTED ELEMENTS
- **REINFORCING COUPLERS MUST BE TESTED**
  - IN ALL LATERAL LOAD RESISTING SYSTEM ELEMENTS, COUPLERS MUST BE TYPE-2
  - NON-STRUCTURAL MEMBERS MAY USE TYPE-1
  - TESTING PROTOCOL MUST BE IN ACCORDANCE WITH ICC OR EQUIVALENT TO PROOF TEST UNDER CYCLIC LOADING
  - COUPLER MUST BE A SYSTEM SLEEVE/GROUT
- **STRUCTURE MUST BE DESIGNED AS PIP STRUCTURE WITH ALL CODE COEFICIENT APPLIED**
  - DESIGN PRECAST EMULATED STRUCTURE USING THE SAME DESIGN PRINCIPALS AS PIP STRUCTURE
  - REINFORCING IS THE SAME EXCEPT WHEN DETAILING THE JOINTS IF IT CHANGES THE ANALYSIS MUST BE RE-RUN WITH THE ACTUAL REINFORCING
  - JOINTS WILL BE DESIGNED TO SATISFY THE DEMAND OR USE SAME REINFORCING CONFIGURATION AS PIP

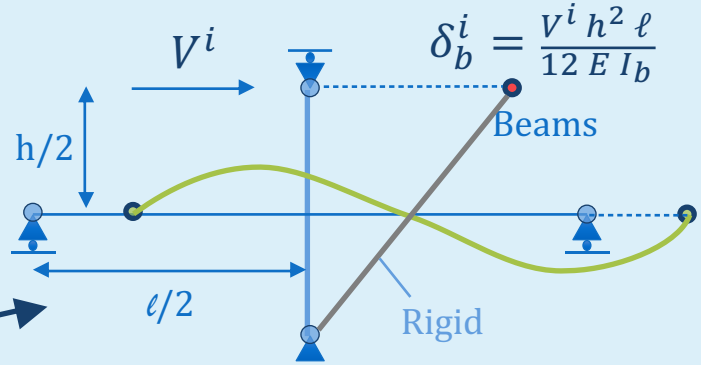
EMULATIVE DESIGN EXAMPLE – NHA PROTOTYPE 5 STORY BUILDING

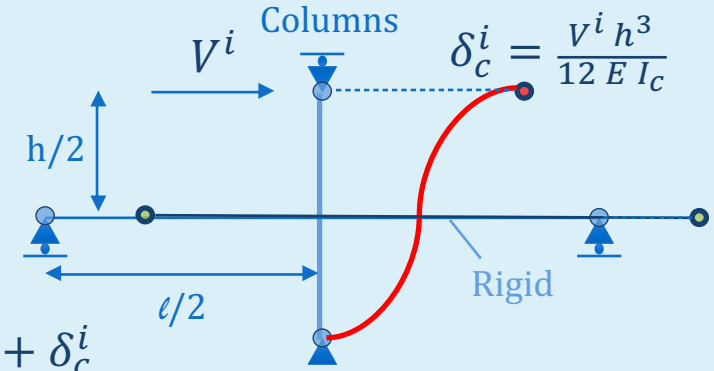


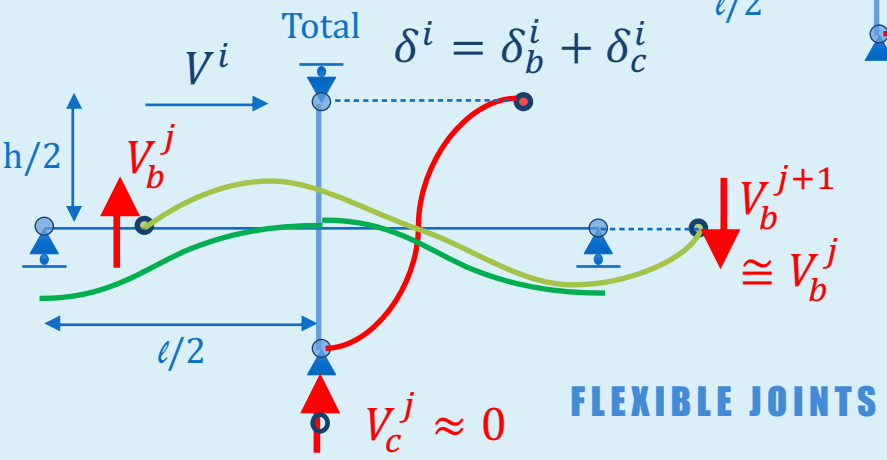
TRANSFER FORCES FROM PRECAST TO CIP – JOINT IS A CONNECTION

EMULATIVE DESIGN EXAMPLE – NHA PROTOTYPE 5 STORY BUILDING









EMULATIVE DESIGN EXAMPLE – NHA PROTOTYPE 5 STORY BUILDING

PROJECT TITLE:
PROPOSED STANDARD 5-STOREY LOW-RISE BUILDING
LOCATION: **VARIOUS LOCATION**

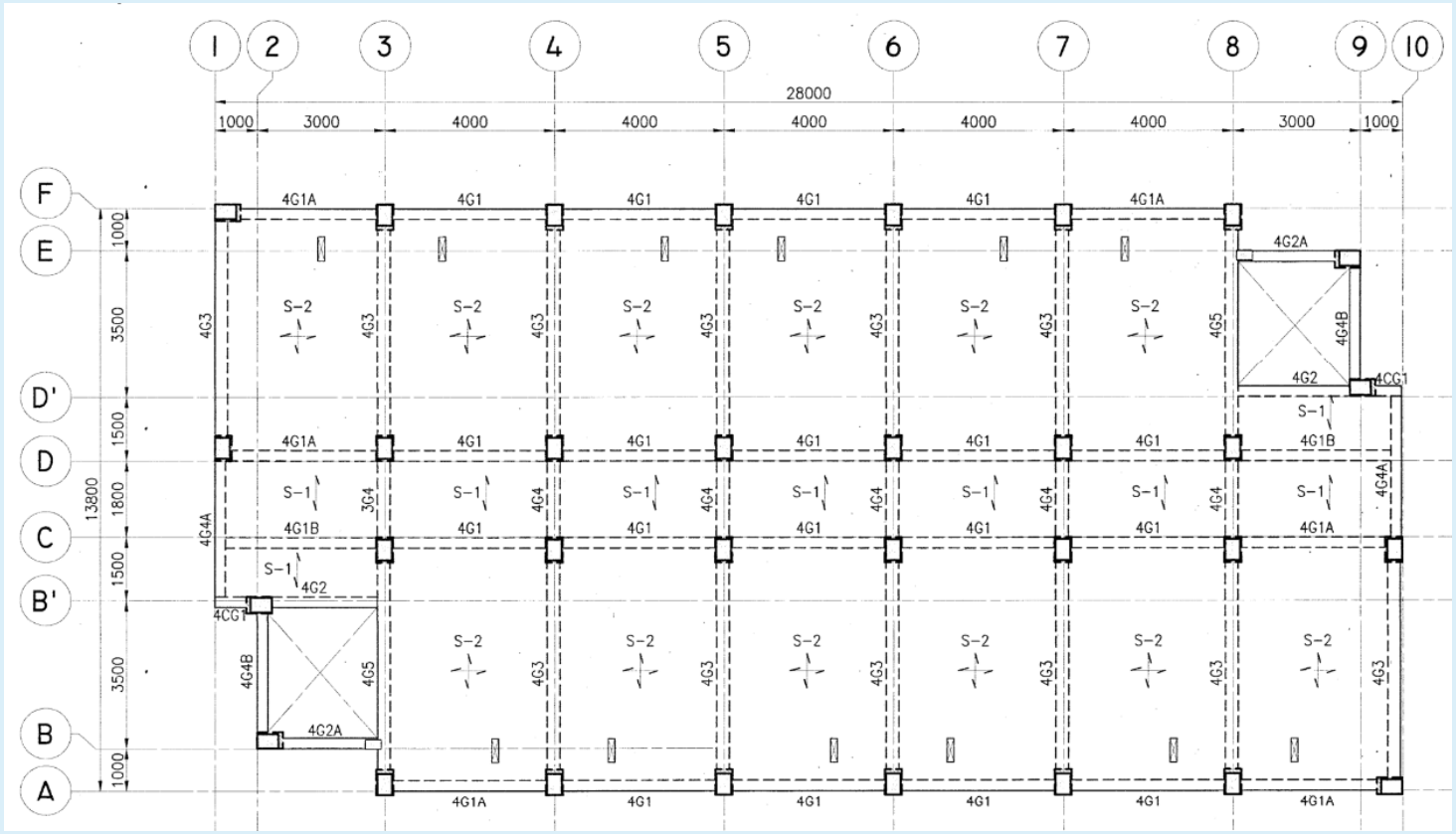
a.c.ong CONSULTING INC.
Engineering + Management
ISO 9001:2015 Certified

A.C.ONG CONSULTING INC.
ALDEN C. ONG M.Eng., ASEP
STRUCTURAL ENGINEER
REG. No.: 68251 DATE: JAN 8, 2019
PTR No.: 7344139 PLACE: MAKATI CITY

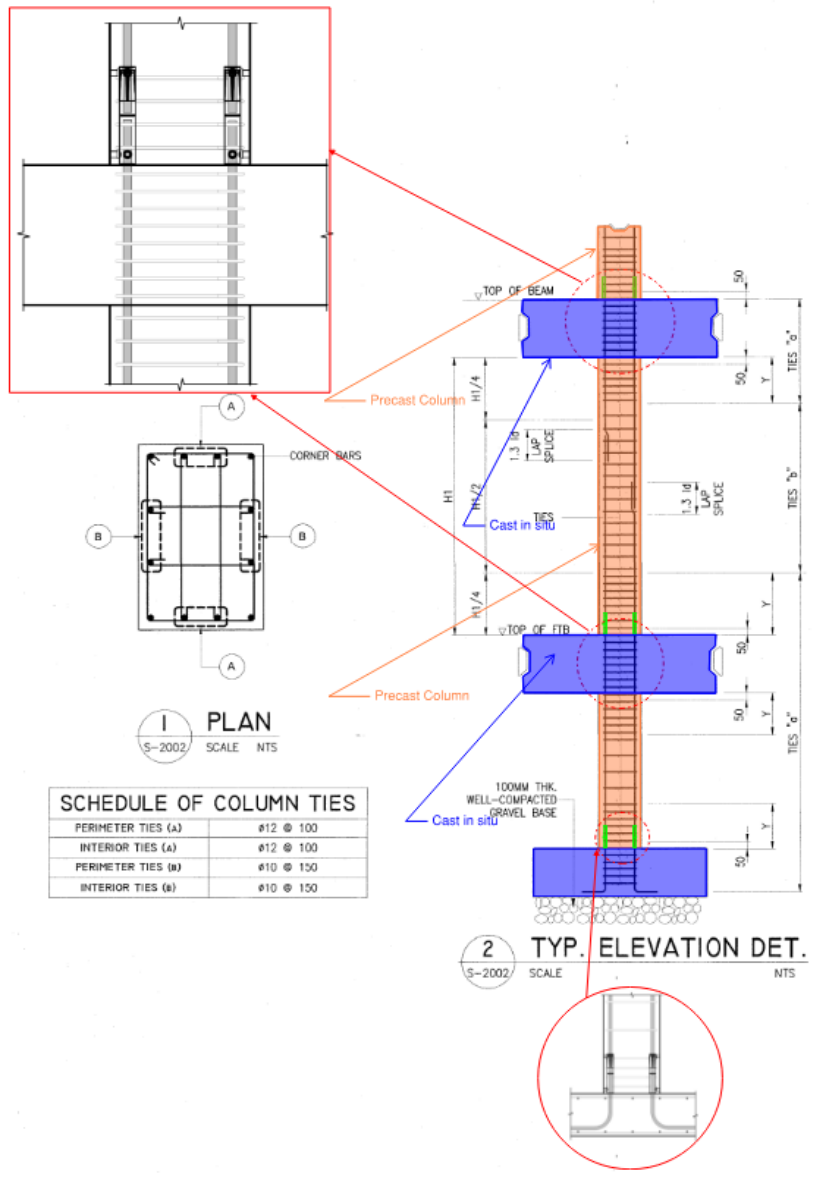
DESIGNED BY: MJAM CHECKED BY: MKBM
DRAWN BY: LRGHWE DATE: JULY 2019
SHEET CONTENT: GENERAL NOTES
REVISIONS: DATE:

Office of the President
NATIONAL HOUSING AUTHORITY
Elliptical Road, Diliman, Quezon City

REVIEWED BY:	SUBMITTED BY:	RECOMMENDING APPROVAL:	APPROVED BY:
JOVITA G. PANOPIO, DIVISION MANAGER A, TRD-HTTRD	EDUARDO SJ. HERRERA, OFFICER-IN-CHARGE, HTTRD	MARIA BENITA O. REGALA, GROUP MANAGER, HSSG	MARCELINO P. ESCALADA, JR., GENERAL MANAGER

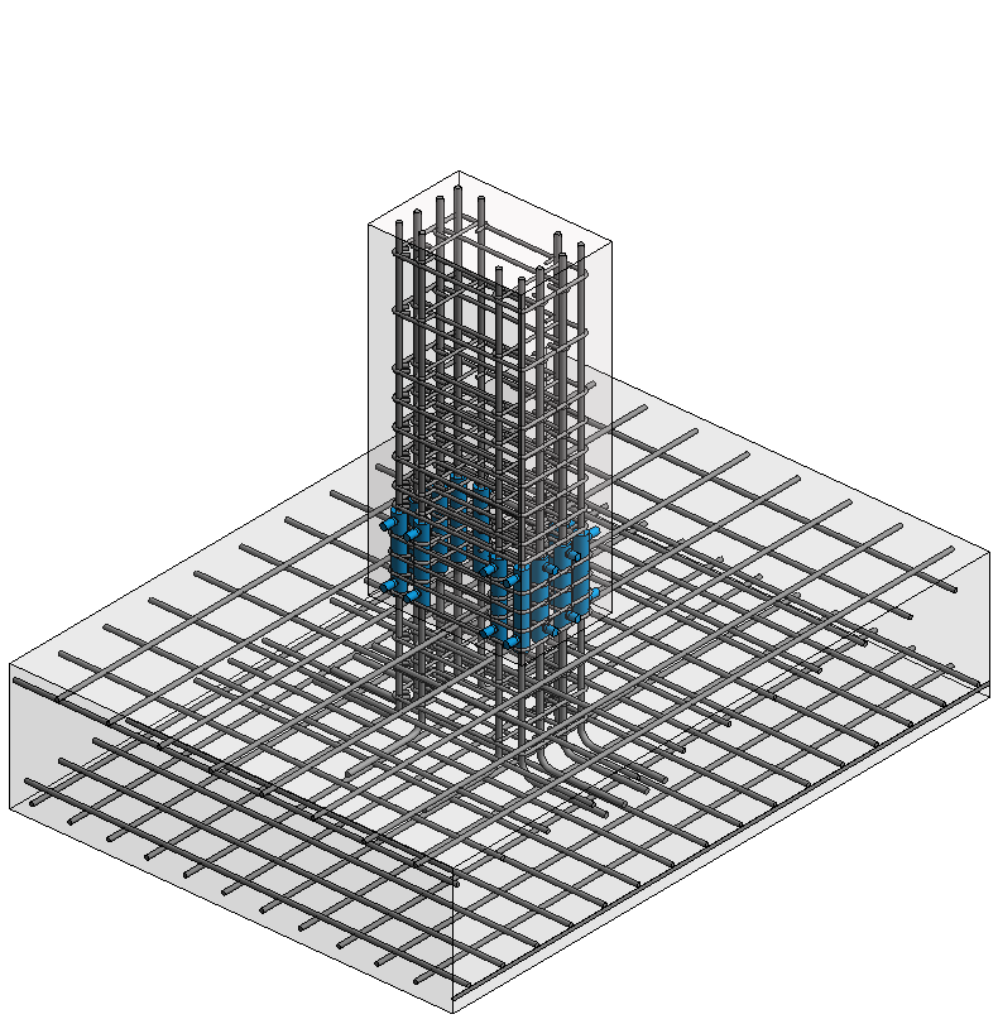


EMULATIVE DESIGN EXAMPLE – PARTIAL – COLUMNS ONLY



- FLOOR SYSTEM
  1. BEAMS PIP
  2. SLABS PIP
- VERTICAL ELEMENTS
  1. PRECAST COLUMNS
  2. PRECAST WALLS
- SECONDARY ELEMENTS
  1. PRECAST FACADE
  2. PRECAST STAIR UNITS

EMULATIVE DESIGN EXAMPLE – PARTIAL – COLUMNS ONLY

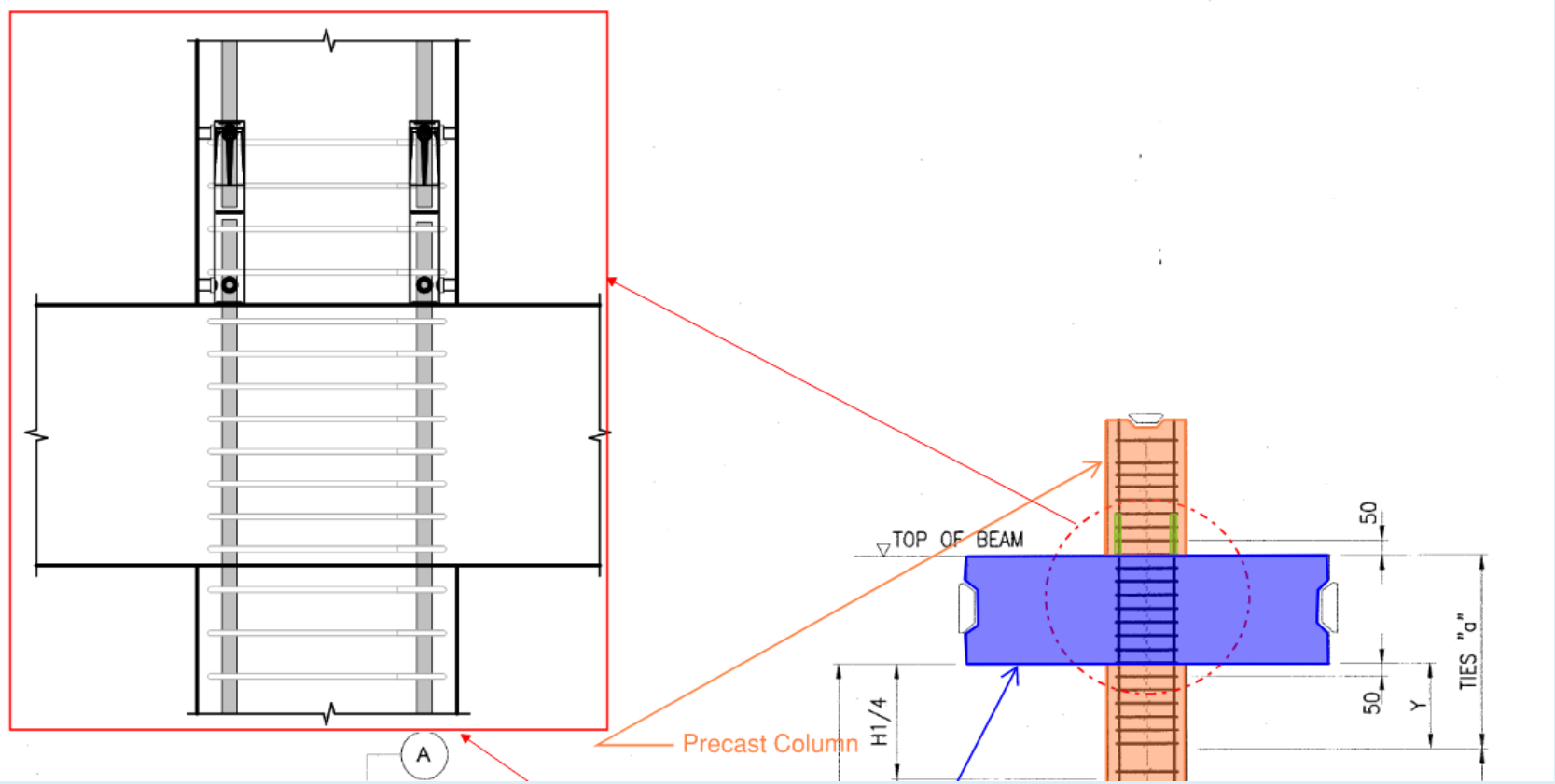


PC COLUMN TO PIP MAT

- FOUNDATION MAT PIP
  1. SPLICING REINFORCING STICKING LESS THAN 300MM ABOVE MAT
  2. NO OTHER SPECIAL CONSIDERATION OF THE MAT
- COLUMN PRECAST
  1. SLEEVES CAST IN THE COLUMN TO MATCH MAT REINFORCING
  2. COLUMN ERECTED AND PROPPED
  3. PUMP GROUT AND GROUT BED

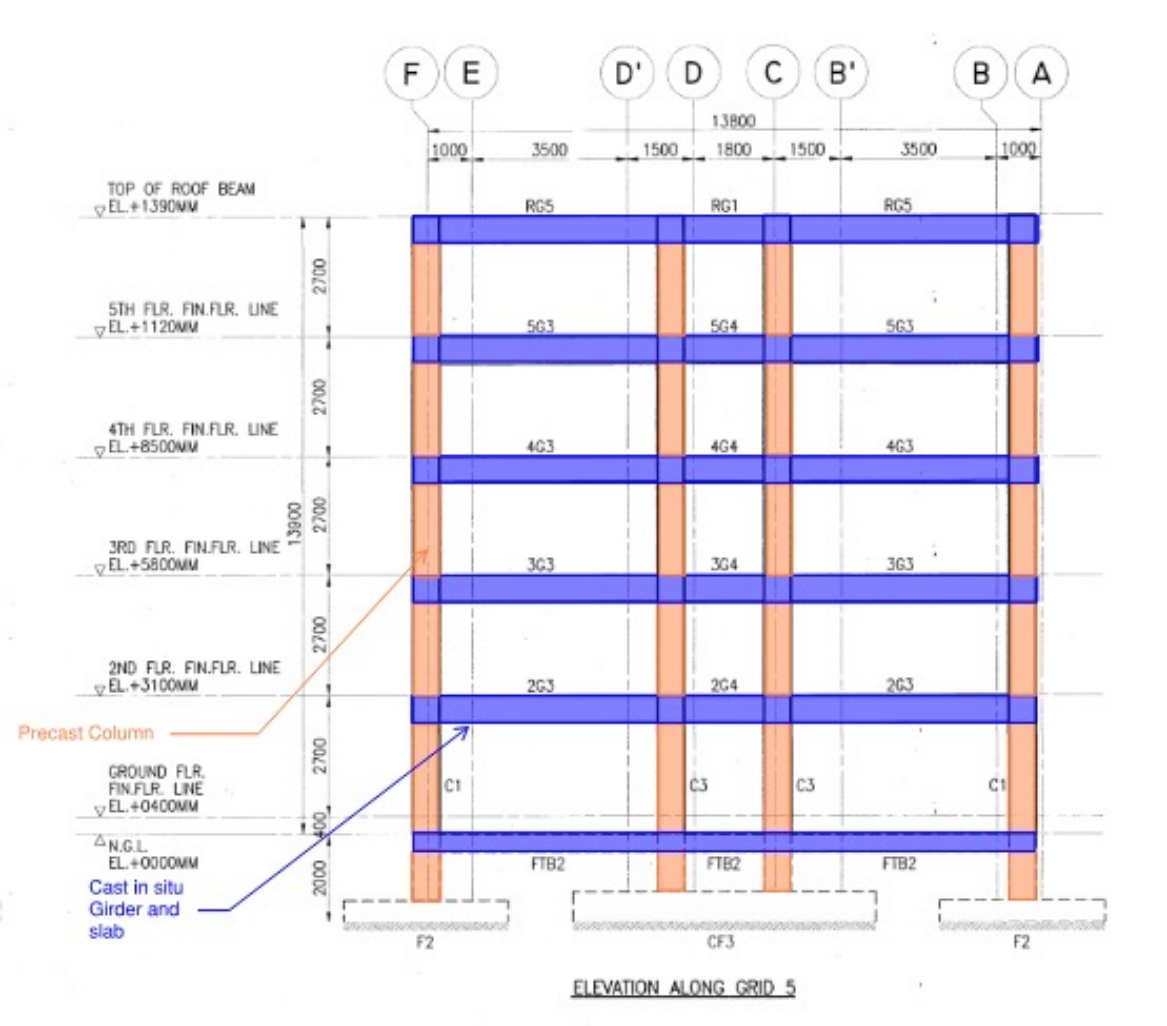
EMULATIVE DESIGN EXAMPLE – PARTIAL – COLUMNS ONLY

- FLOOR BEAM/SLABS CAST PIP
  1. PRECAST COLUMN WILL HAVE IT OWN REINFORCING BRIDGING THE FLOOR AND STICK ABOVE <300MM
  2. NO CHANGE TO THE FLOOR SYSTEM



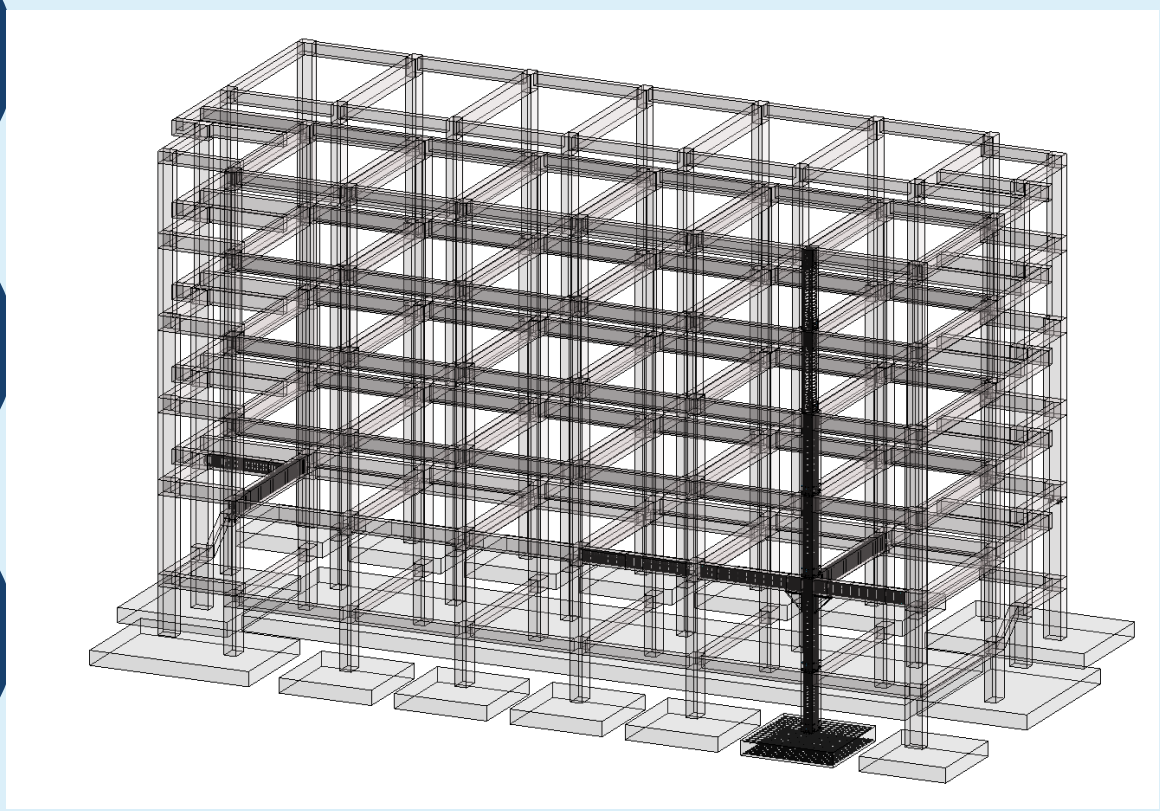
PC COLUMN TO FLOOR

EMULATIVE DESIGN EXAMPLE – PARTIAL – COLUMNS ONLY



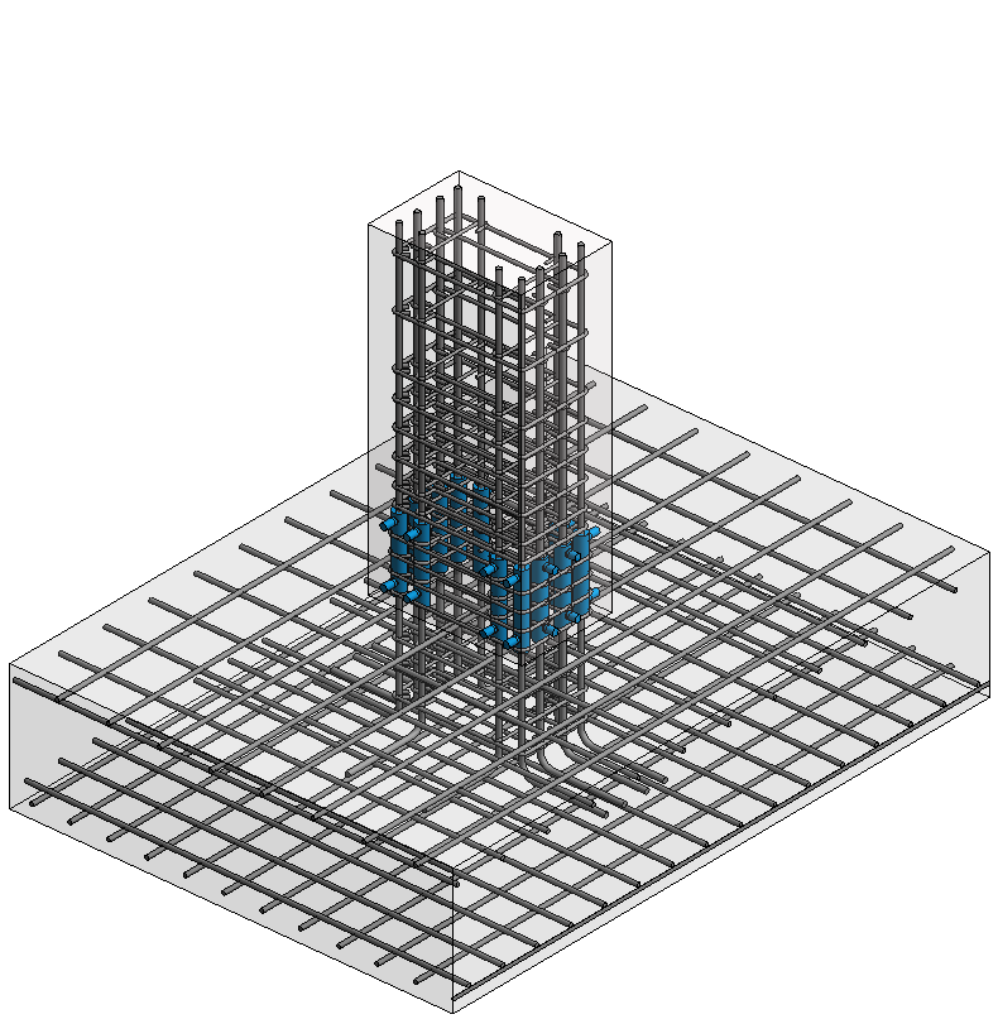
PC COLUMN FINAL FRAMING

EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST



- FLOOR SYSTEM
  1. BEAMS - PRECAST
  2. SLABS - PRECAST HALF SLABS OR HOLLOWCORE W/ TOPPING
- VERTICAL ELEMENTS
  1. PRECAST COLUMNS
  2. PRECAST WALLS
- SECONDARY ELEMENTS
  1. PRECAST FACADE
  2. PRECAST STAIR UNITS

EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST



PC COLUMN TO PIP MAT

- FOUNDATION MAT PIP
  1. SPLICING REINFORCING STICKING LESS 300MM ABOVE MAT
  2. NO OTHER SPECIAL CONSIDERATION OF THE MAT
- COLUMN PRECAST
  1. SLEEVES CAST IN THE COLUMN TO MATCH MAT REINFORCING
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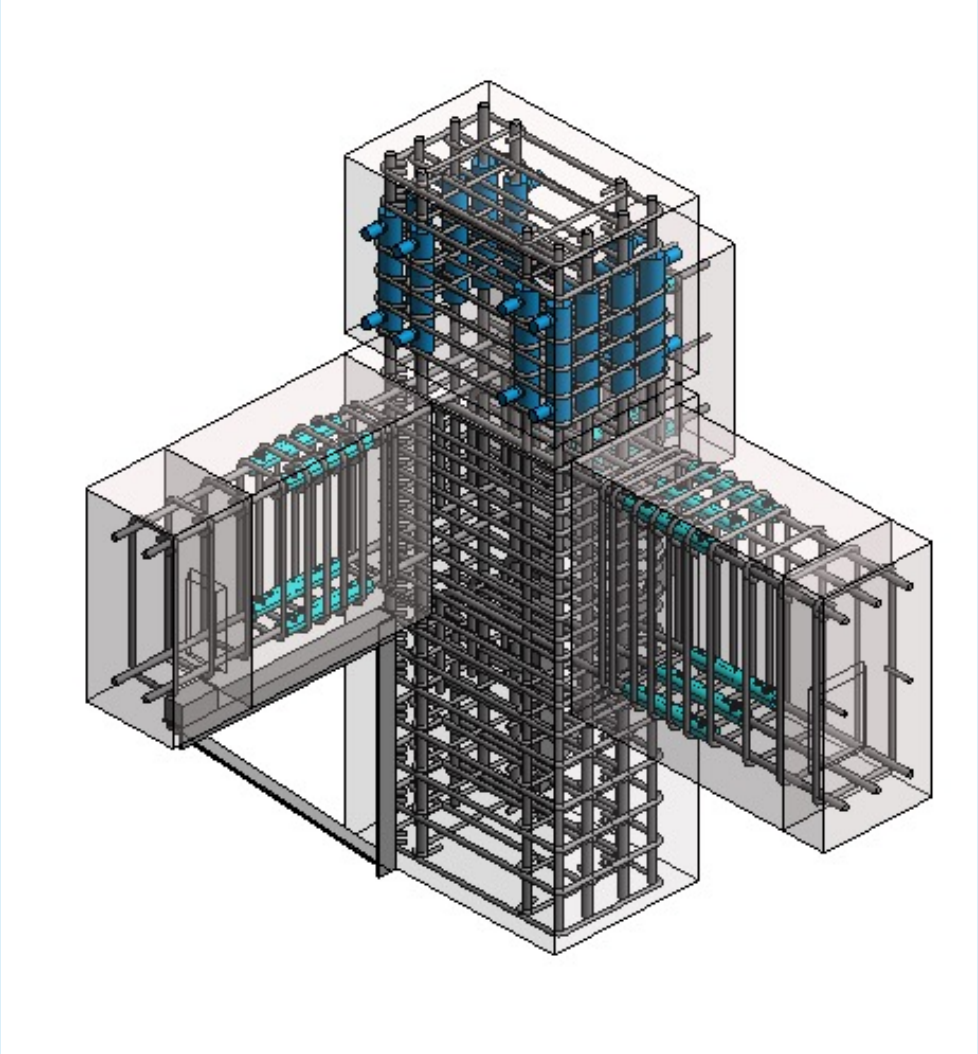
  3. PUMP GROUT AND GROUT BED

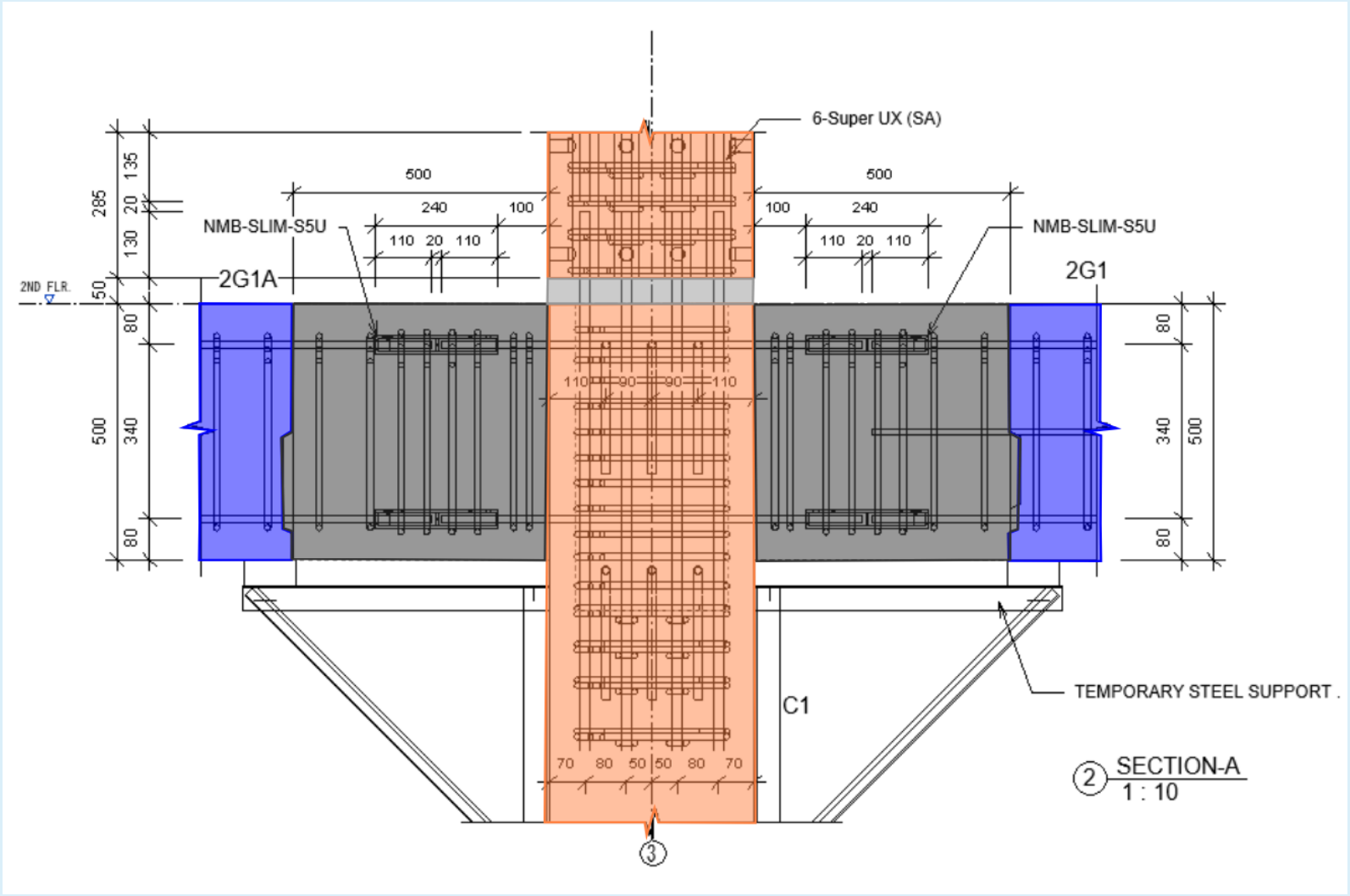
EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST



BEAM COLUMN JOINT

- COLUMN TO COLUMN
  1. 50MM GROUTED JOINT
  2. REBAR SPLICED WITH REINF. PROJECTING <300MM
- BEAM TO COLUMN
  1. WET JOINT 500MM LONG
  2. REINFORCING OUT OF COLUMN
  3. SPLICE REINF. HORIZONTALLY
  4. FORM JOINT AND POUR CONCRETE

EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST



BEAM COLUMN JOINT

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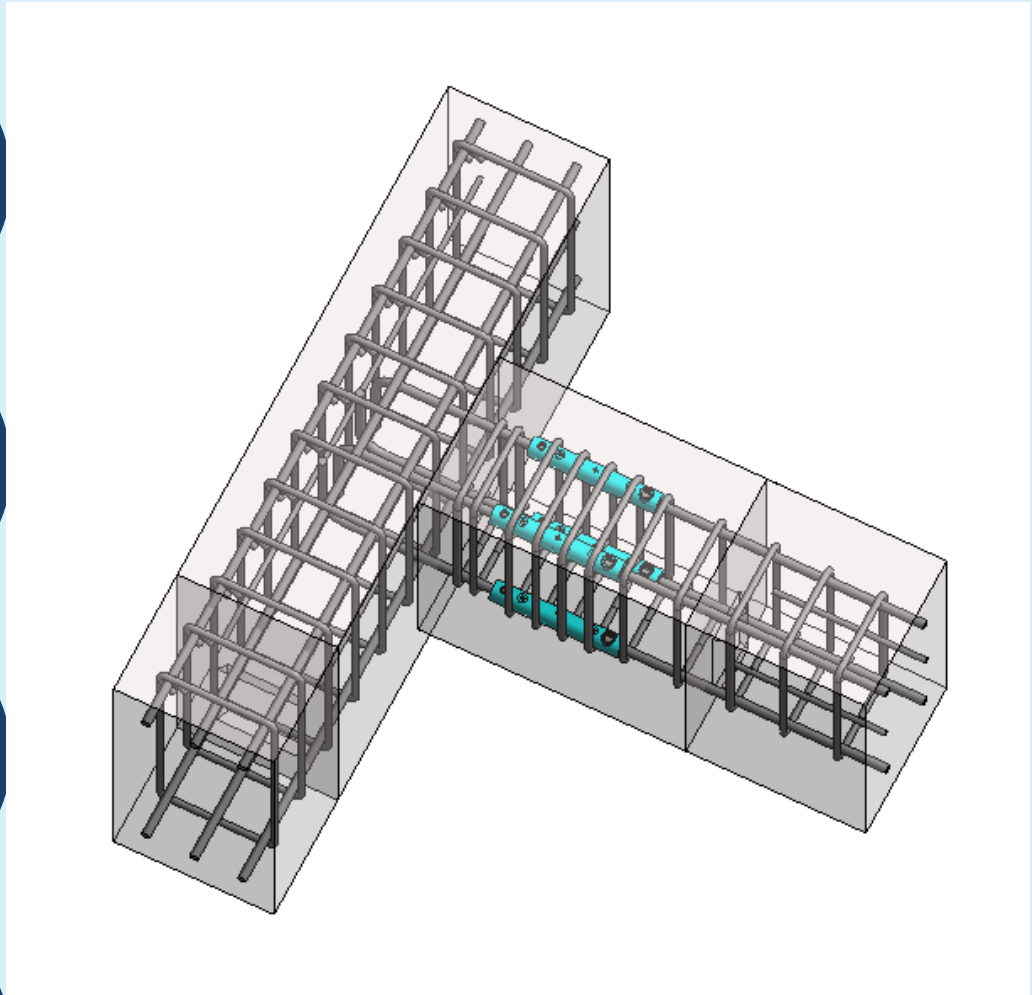
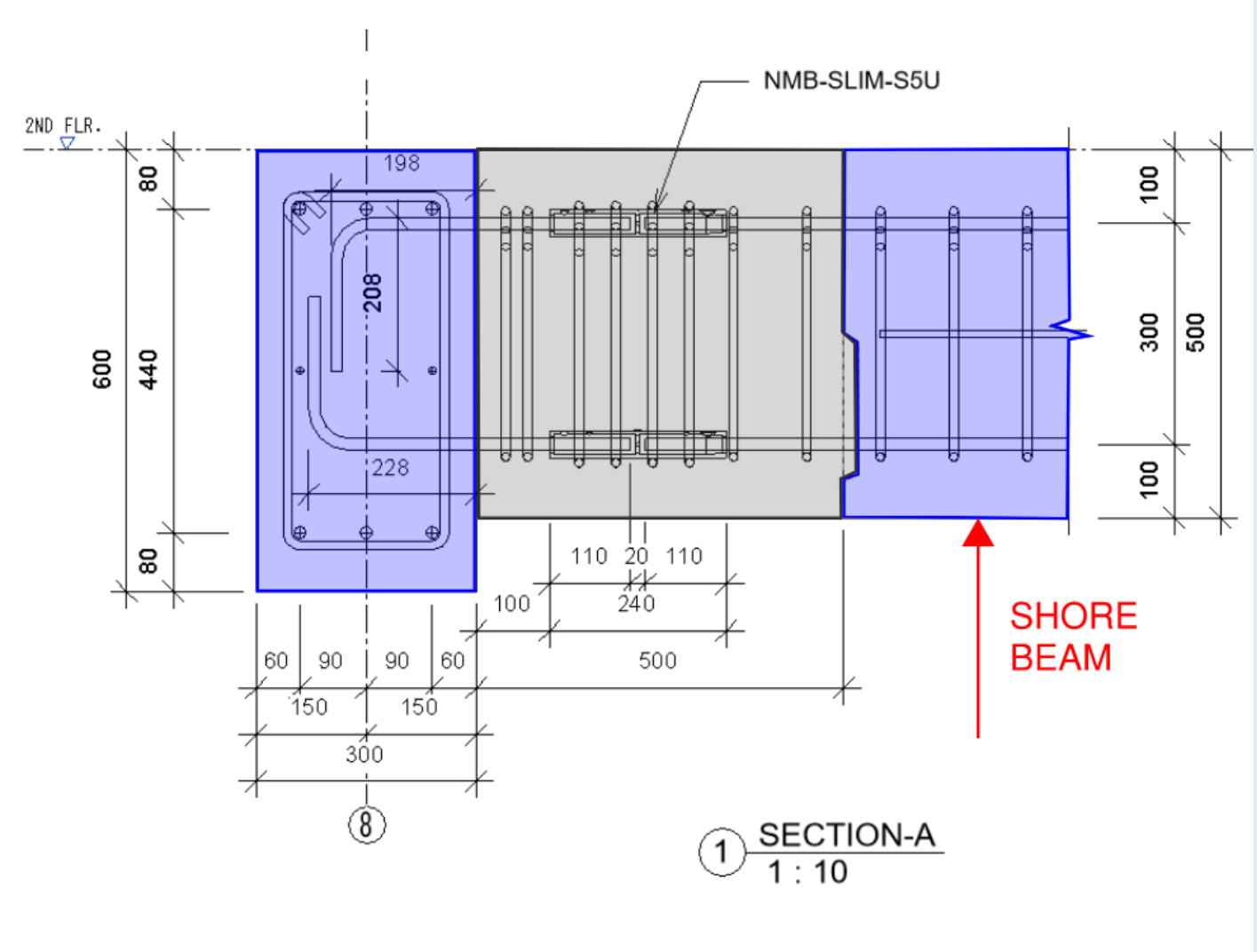


- GIRDER
  1. REBAR SPLICED WITH REINF. PROJECTING <300MM
- BEAM TO GIRDER
  1. WET JOINT 500MM LONG
  2. REINFORCING OUT OF GIRDER
  3. SPLICE REINF. HORIZONTALLY
  4. SHORE BEAM
  5. FORM JOINT AND POUR CONCRETE

TRANVERSE BEAM TO GIRDER JOINT

EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST



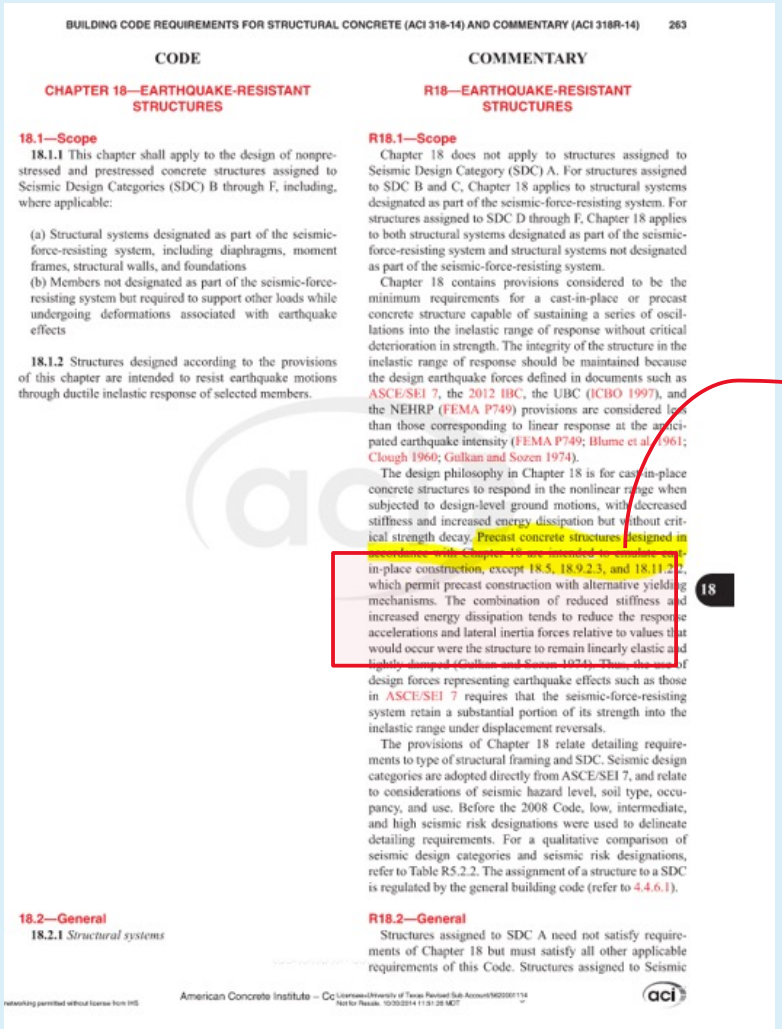
BEAM TO GIRDER JOINT

EMULATIVE DESIGN EXAMPLE – TOTAL PRECAST

- DIAPHRAGM
  1. DRY PRECAST DIAPHRAGM IS HARD TO ACHIEVE BUT POSSIBLE USING ASCE7-16 PRECAST DIAPHRAGM PROVISIONS
- IDEALIZED DEEP BEAM PIP DIAPHRAGM IS THE MOST USED. THE TOPPING OVER PRECAST SHOULD BE AT LEAST 85MM
  1. DESIGN FOR FULL DEPTH OF DIAPHRAGM BUT REINFORCE TOPPING ONLY FOR CHORD AND SHEAR FORCES
  2. PRECAST TIE BACK TO DIAPHRAGM MUST CONFORM TO ALL ACI INTEGRITY REQUIREMENTS

NON-EMULATIVE DESIGN

- GOVERNING CODE ACI-318·18.1.2 ALLOWS NON PRESCRIPTIVE PRECAST STRUCTURES



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Chapter 18 contains provisions considered to be the minimum requirements for a cast-in-place or precast concrete structure capable of sustaining a series of oscillations into the inelastic range of response without critical deterioration in strength. The integrity of the structure in the inelastic range of response should be maintained because the design earthquake forces defined in documents such as ASCE/SEI 7, the 2012 IBC, the UBC (ICBO 1997), and the NEHRP (FEMA P749) provisions are considered less than those corresponding to linear response at the anticipated earthquake intensity (FEMA P749; Blume et al. 1961; Clough 1960; Gulkan and Sozen 1974).

The design philosophy in Chapter 18 is for cast-in-place concrete structures to respond in the nonlinear range when subjected to design-level ground motions, with decreased stiffness and increased energy dissipation but without critical strength decay. Precast concrete structures designed in accordance with Chapter 18 are intended to emulate cast-in-place construction, except 18.5, 18.9.2.3, and 18.11.2.2, which permit precast construction with alternative yielding mechanisms. The combination of reduced stiffness and increased energy dissipation tends to reduce the response accelerations and lateral inertia forces relative to values that would occur were the structure to remain linearly elastic and lightly damped (Gulkan and Sozen 1974). Thus, the use of design forces representing earthquake effects such as those in ASCE/SEI 7 requires that the seismic-force-resisting system retain a substantial portion of its strength into the inelastic range under displacement reversals.

The provisions of Chapter 18 relate detailing requirements to type of structural framing and SDC. Seismic design categories are adopted directly from ASCE/SEI 7, and relate to considerations of seismic hazard level, soil type, occupancy, and use. Before the 2008 Code, low, intermediate, and high seismic risk designations were used to delineate detailing requirements. For a qualitative comparison of seismic design categories and seismic risk designations, refer to Table R5.2.2. The assignment of a structure to a SDC is regulated by the general building code (refer to 4.4.6.1).

R18.2—General

Structures assigned to SDC A need not satisfy requirements of Chapter 18 but must satisfy all other applicable requirements of this Code. Structures assigned to Seismic

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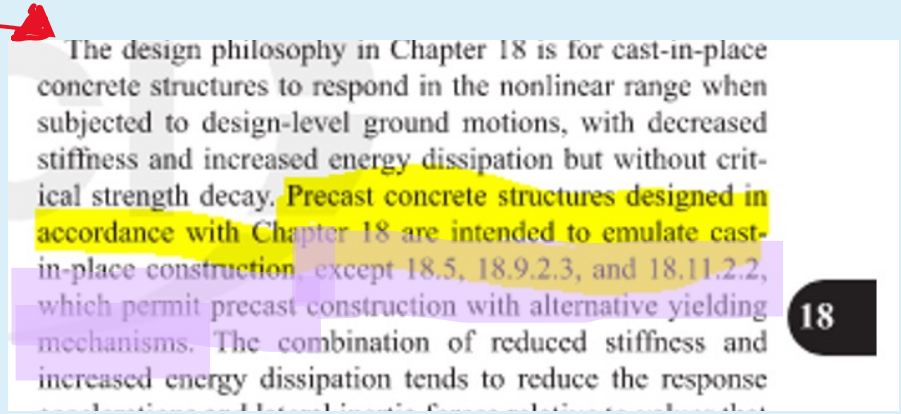

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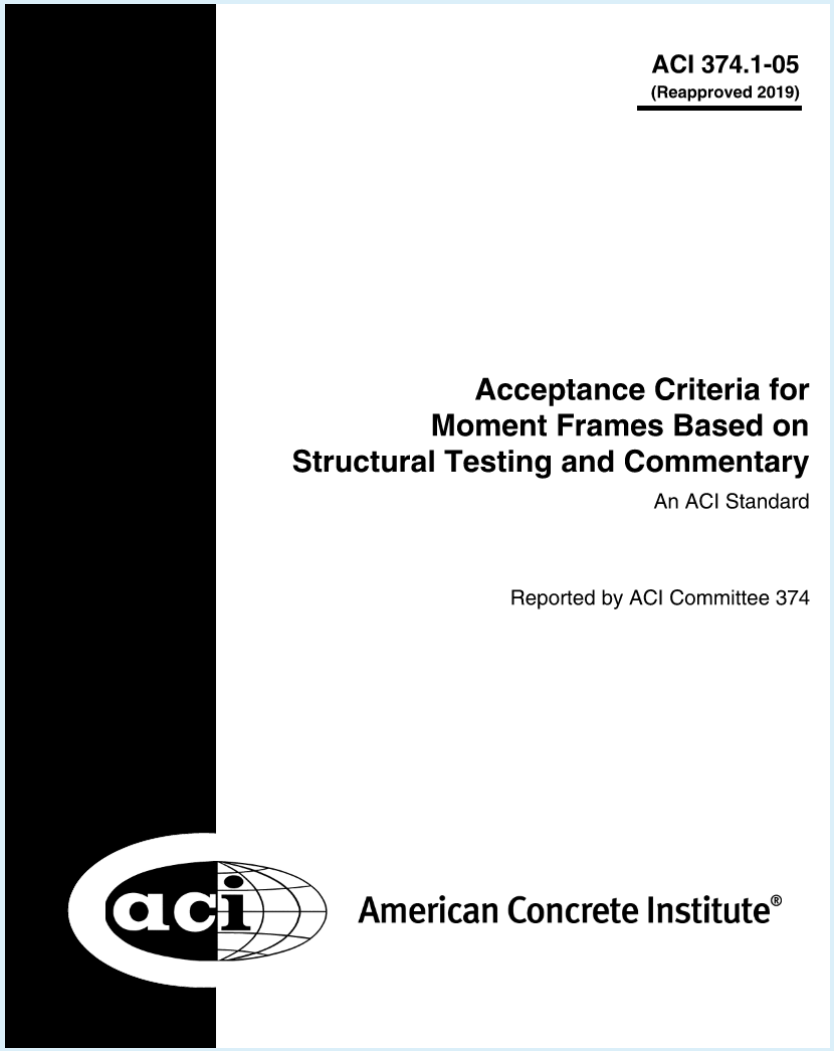
NON-EMULATIVE DESIGN

- **NON-EMULATIVE WITH ACI CODE PROVISIONS**
  - DESIGN JOINTS USING ACI CODE WITH PRECAST THAT DO NOT PRESCRIBE TO THE FULL REQUIREMENTS OF ACI-318
    1. THE GOVERNING DOCUMENT IS ACI-374
    2. TESTING IS REQUIRED TO MEET 3.5% DRIFT ON A PROGRESSIVE CYCLIC LOADING
    3. ACCEPTANCE CRITERIA IS DUCTILITY BASED

NON-EMULATIVE DESIGN

- NON MULATIVE WITH ACI CODE PROVISIONS



NON-EMULATIVE DESIGN

- NON EMULATIVE WITH ACI CODE PROVISIONS

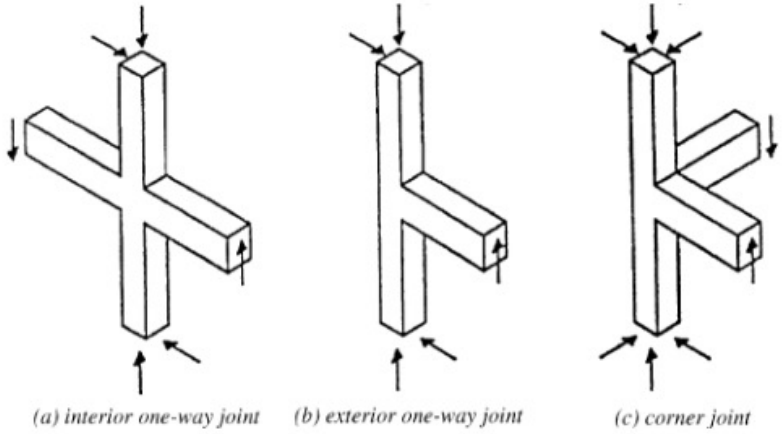


Fig. R5.1—Characteristic intersection configurations and test actions.

SPECIMENS

TESTING

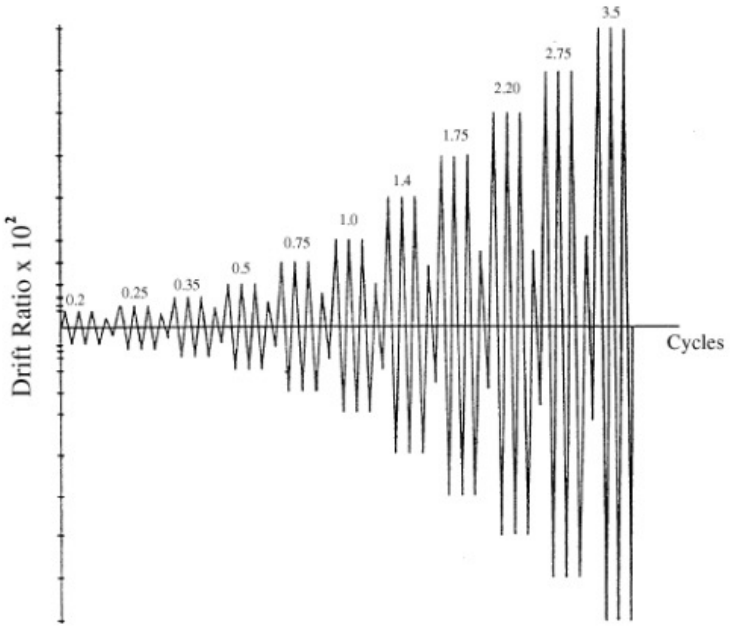


Fig. R7.0—Example of test sequence of displacement controlled cycles.

NON-EMULATIVE DESIGN

- NON EMULATIVE WITH ACI CODE PROVISIONS

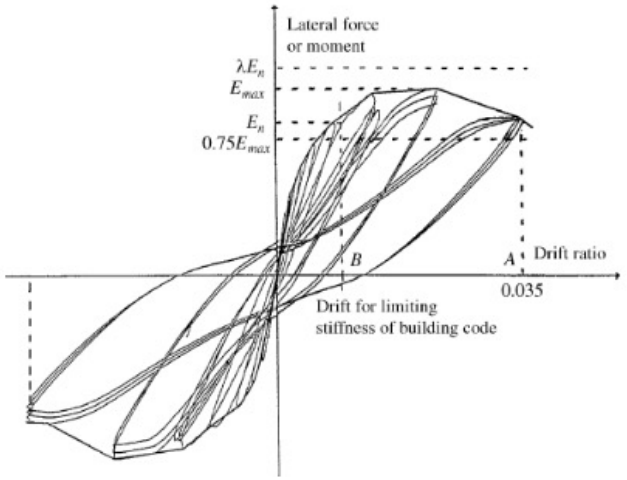


Fig. R9.1—Quantities used in evaluating acceptance criteria.

ACCEPTANCE

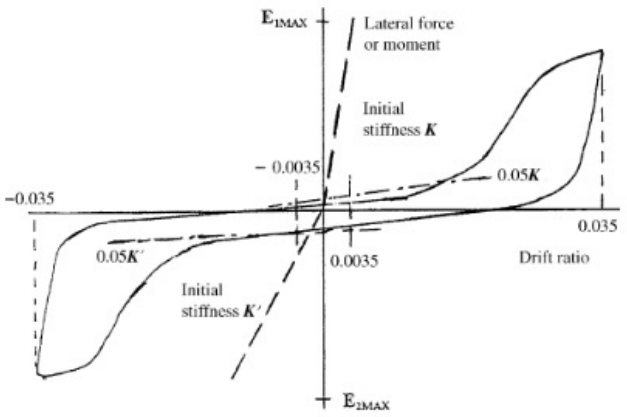


Fig. R9.1.3—Unacceptable hysteretic behavior.

NON-EMULATIVE DESIGN

- NON-EMULATIVE WITHOUT ACI CODE PROVISIONS
  - DESIGN IS PERFORMANCE-BASED DESIGN – EXAMPLE PCI PRESS PROGRAM
    1. ACTUAL JOINT BEHAVIOR MUST BE USED IN THE ANALYSIS
    2. ACTUAL SPECTRAL ANALYSIS REQUIRED
    3. DETAILING MUST FOLLOW TESTED SYSTEM
    4. PROOF TESTING IS REQUIRED
    5. ACCEPTANCE CRITERIA APPROVED AND DICTATED BY BUILDING OFFICIALS

- NOT RECOMMENDED EXCEPT FOR SPECIAL PROJECTS

CONCERNS

- **DESIGNERS, OWNERS AND PRECASTERS**

  - DESIGNER'S CONCERNS
    1. CANNOT INSPECT PRECAST THE SAME WAY PIP IS INSPECTED
    2. DESIGN TOOLS
    3. LIABILITY/RISK

  - SOLUTIONS
    1. ADD INSPECTION TO YOUR CONTRACT
    2. DO INSPECTIONS YOURSELF AT PRECAST PLANT AND FIELD
    3. DEMAND 3RD PARTY INSPECTOR REPORT TO YOU

CONCERNS

- DESIGNERS, OWNERS AND PRECASTERS

  - OWNER'S CONCERNS
    1. PROOF OF CONCEPT
    2. VERIFY QUALITY
    3. SPECIFICATIONS AND DOCUMENTATIONS

  - SOLUTIONS
    1. DESIGNERS NEED TO PRESENT PROOF OF CONCEPT
    2. PRECASTER SHOW DETAILS EQUIVALENCY
    3. PRECASTER TO DEMONSTRATE THE ABILITY TO PRODUCE, STORE, SHIP AND ERECT HIGH QUALITY PRODUCTS

CONCERNS

- **DESIGNERS, OWNERS AND PRECASTERS**

  - PRECASTER'S CONCERNS
    1. LACK OF DOCUMENTATION
    2. EXPENSIVE TESTING
    3. AVAILABILITY OF TRAINED SKILLED LABOR FORCE

  - SOLUTIONS
    1. PRECASTERS SHOULD FORM AN ASSOCIATION PCMAP FOR EXAMPLE, PRECAST MANUFACTURERS ASSOCIATION OF PHILIPPINES, SIMILAR TO PCI, JPCI
    2. WRITE DOCUMENTS FROM EXISTING SOURCES TO ADDRESS DESIGN, QUALITY CONTROL AND ERECTION SAFETY
    3. COORDINATE WITH ASEP TO HAVE A RECOGNIZABLE DOCUMENT FOR PRECAST DESIGN IN THE PHILIPPINES

THANKS TO THE AUDIENCE

QUESTIONS?

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