SIMPLIFIED ANALYSIS AND DESIGN CONSIDERATIONS OF PRECAST JOIST IN ONE WAY RIBBED SLAB

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This is to certify that the thesis prepared by Sophonyas Asrat, entitled: *Simplified Analysis and Design Considerations of Precast Joist in One Way Ribbed Slab* and submitted in partial fulfillment of the requirements for the degree of Degree of Master of Science (Structural Engineering) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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To my Families

ABSTRACT

Simplified Analysis and Design Considerations of Precast Joist in One Way Ribbed Slab

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The design and analysis of a structural member requires the understanding of the possible loads that act on the system in the life span of the structure. For this reason, the stage of construction of precast joist is classified into two, initial stage and final stage. For each stage this study covers the ultimate resistance of the members and deflection control, to incorporate the limit state design requirements.

Precast joist is used in one way ribbed slab and premature failure should be avoided in the life span of the precast joist. In this study, this is addressed by providing appropriate size of members for the initial stage and final stage, and by supporting the precast joist in the initial stage by temporary intermediate supports.

A total of thirty two types of precast joist are modeled, analyzed and designed. Since up to three temporary intermediate supports are provided in the initial stage for each type of precast joist, the total number of models becomes one hundred twenty eight. The result of the study shows that all of them can survive the initial stage of construction if appropriate number of temporary intermediate support is provided. However, only half of them satisfy the ultimate state requirement in the final stage.

Key words: Precast joist, Initial stage, Final stage, Temporary intermediate support, Ultimate limit states, and Serviceability limit states.

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Success is the array of input from so many. No achievement in life is without the help of many known and unknown individuals who have impacted our lives.

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NOTATIONS

A	Cross-sectional area
A_s	Area of the tension reinforcement
A_v	The area shear reinforcement within a distance s
b_w	Width of the web of a member
C	Axial load (Compression)
	Central support of the precast joist in the initial stage
c/c	Centre to Centre
C_c	compressive force developed in the concrete
C_s	compressive force developed in the compression reinforcement
d	Effective depth of the section
D	Total depth of a cross section
E	End support of the precast joist in the initial stage
E_{cm}	Short term elastic modulus of concrete
E_s	Modulus of elasticity of steel
f_{cd}	Design compressive strength of concrete
f_{ck}	Characteristic cylinder compressive strength of concrete
f_{ctd}	Design tensile strength of concrete
f_{ctk}	Characteristic tensile strength of concrete
f_y	Yield stress
f_{yk}	Characteristic strength of the reinforcement
i	Radius of gyration
I_i	Moment of inertia of the uncracked transformed concrete section
L	Length, system length, span length
L_e	Effective span
$M_{y,sd}$	Design value of bending moment about the major axis
$M_{z,sd}$	Design value of bending moment about the minor axis
M	Middle support of the precast joist in the initial stage

	Internal moment
N_{sd}	Design value of axial force
P	Concentrated point load at a joint
r	Radius of a steel bar
s	Shear reinforcement spacing in the direction of the longitudinal reinforcement
T	Axial load (Tension)
T_s	Tensile force developed in the tension reinforcement
V_c	Shear Carried by the concrete
V_S	Shear resistance of vertical stirrups
$W_{el,y}$	Elastic section modulus about the major axis
$W_{el,z}$	Elastic section modulus about the minor axis
$W_{pl,y}$	Plastic section modulus about the major axis
$W_{pl,z}$	Plastic section modulus about the minor axis
x	Neutral axis depth at the section of maximum moment
z	Internal lever arm at the section of maximum moment
Z	Section modulus
α	Factor, imperfection factor
α_c	Relative compressive force in concrete
β_a	Constant value for different structural member and support condition
β_A	Factor
β_c	Relative distance of point of application of the compressive force in concrete, C_C, from the outermost concrete fibers under compression
β_M	equivalent uniform moment factor for flexural bucking
γ	Unit weight
γ_c	Partial safety factor for concrete
γ_{M1}	Partial safety factor for material
γ_S	Partial safety factor for reinforcing steel

δ	Deflection
ε_c	Strain in the concrete fiber
ε_{cm}	Compressive strain in outer most concrete fiber
ε_s	Strain in the tension reinforcement
ε_{sc}	Strain in the compression reinforcement
λ	Slenderness
$\bar{\lambda}$	In plane non dimensional slenderness ratio calculated using a buckling length equal to the system length
μ_y, μ_z	factors
ρ	Geometrical ratio of reinforcement
σ_{sc}	Stress developed in the compression reinforcement
Φ	Diameter of a steel bar
ω	Uniformly distributed line load
χ_y, χ_z	Reduction factor corresponding to the relevant axis
χ_{min}	Smaller reduction factor
Ψ	Ratio of end moment

1. INTRODUCTION

Precast concrete construction is a controlled operation executed under ideal conditions of formwork, casting, vibration, curing and inspection. The design considerations in case of precast concrete involve analysis that is not required in conventional design practices. The designer must be familiar with various stages of construction and should meticulously plan the complete and specific design detail accordingly.

The Stage of construction of the precast beam can be broadly classified into two with respect to the load imposed on it, Initial stage and final stage. The initial stage has three sub-stages: erection stage, block laying stage and concrete pouring stage. [8]

1.1. LITERATURE REVIEW

In the current practice for the construction of precast joist in one way ribbed slab, the precast joist faces premature failure. In addition, there is lack of consistency with respect to size of reinforcement and number of temporary intermediate support provided in the initial stage, for construction of building of the same category and span length. In this thesis, the widely used size of reinforcement and the commonly used number of temporary intermediate support are used to avoid premature failure and to choose the most economical section, with respect to the minimum usage of reinforcement, which satisfies the safety requirement according to the Ethiopian building code of practice.

The aim of this thesis is to prepare a clear guideline to check and design a precast joist system of any size by using the procedure followed for selected models that are commonly used on residential building sites.

Previously, the precast joist used in Ethiopia was studied by other post graduate students.

In June 2002, Admasu Shimeles [7] has studied the advantage of precast joist in one way ribbed slab by comparing with the solid slab system. And he concluded that the precast joist system has both advantage with respect to economy and preserves the national resource by avoiding excessive use of formwork. He also discusses the necessity of the temporary intermediate support in the initial stage of construction for satisfying the ultimate limit state requirement.

In July 2004, Merid Belay [14] has studied a simplified precast beam slab system which reduces the use of formwork from the usual way of construction techniques. In general the thesis covers the determination of economical section and maximum span of composite section. In his study, he mentioned the provision of an intermediate support which he concludes that, it affects the top reinforcement size requirement. In addition, he made cost comparison of the ribbed slab, solid slab and the composite beam/slab system; which is done only on the cost of the slab, without including the cost effect on other structural members. He concludes that the precast beam/slab system is a more economical section when used for small span building, but can be used up to 8.5m span, however, the saving decrease as the span increases.

In July 2006, Matheas Kebede [6] has done his work for the initial loading condition to carry out experiment for investigating the response of pre-cast beams commonly used in construction. He also carried out the cost comparison between the solid slab system and slab system with precast joist. In the experiment, it is observed that failure is initiated by buckling of stirrups around the supports where the maximum shear and maximum moment acts simultaneously and the mode of failure is shear buckling failure.

In November 2009, Melaku Tesfaye [8] has studied the precast beam system using plane truss system and the analysis was done by SAP 2000 and checks both the Serviceability limit state and Ultimate limit state requirement.

In this thesis, as clearly specified in the objective, the different failure mode of the precast system is identified for all the models in the initial stage. In addition, the effect of the temporary intermediate support for all the selected models is considered both for the Serviceability Limit State and Ultimate Limit State.

1.2. OBJECTIVES OF THE STUDY

The general objectives of the study are:

i. To prepare a computer model for the initial stage that simulate the behavior of the precast beam element

ii. To mechanistically understand the real behavior of precast beam element

iii. To prepare a guideline that ensures the avoidance of premature failure[1] modes.

The specific objectives of the study are:

i. To access the condition in which buckling of top reinforcement, buckling of stirrups, yielding of bottom reinforcement that occurs in the initial stage, and to study all the models up to the final stage.

ii. To determine the number of temporary intermediate supports required for the initial stage of construction of the precast joist.

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[1]Premature failure modes are buckling of top reinforcement and buckling of stirrups.

1.3. SCOPE OF THE STUDY

In this study the analysis and design of the precast joist is done at a theoretical level and Laboratory test is not executed.

In all models of the initial stage, the only difference is the size of the reinforcement, but the spacing and the placement is the same. The steel bar size used in the study are Ø6, Ø8, Ø10, Ø12 or Ø14 for longitudinal reinforcement, and Ø6 c/c 150 or Ø8 c/c 150 for Stirrup. The decision for size and placement of the reinforcement is done on the basis of the commonly used arrangement and size of steel bars for the current construction.

2. THEORETICAL INVESTIGATION

2.1. GENERAL

A structure, part of a structure, is considered unfit for use when it exceeds a particular state called limit state, beyond which it infringes one of the criteria governing its performance or use. The limit states can be placed into two categories: the ultimate limit states and the serviceability limit states. [3] The study includes the serviceability requirement for deflection and the ultimate limit state requirement for both the initial and final stages of the construction. According to EBCS-2, 1995 the deflection requirement of any part of a structure may be ensured by keeping the calculated value below limit or by compliance with the requirement for a minimum effective depth. The deflection of the system in the initial stage is computed by using the structural software, ETABS Nonlinear V.9.7.4., and for the final stage the compliance of the effective depth of the section with the minimum effective depth is done.

To achieve the objective of the study, the thesis considers both the initial and final stage. In the initial stage up to three temporary intermediate supports are provided in order to have a system which is safe and functional. The analysis and design of the initial stage is done using structural software ETABS Nonlinear V.9.7.4. and the design output of some selected members has been checked manually according to EBCS -3, 1995. The analysis of the final stage is done by using an elastic method and the design of the final stage has been done by considering the capacity of the section in the inelastic stage according to EBCS - 2, 1995.

2.2. MODELING

The precast joist system in the initial stage is modeled as a 3-d frame system using ETABS Nonlinear v9.7.4, since the members of the precast joist are welded on site.

In the initial stage up to three intermediate supports is provided for all the selected models as shown in Fig.4.2, Fig.4.3, Fig.4.4 and Fig.4.5

The load acting on the precast joist system for all sub-stages of the initial stage is converted to an equivalent joint load and in the final stage it is converted to an equivalent uniform line load.

2.3. DESIGN CONSTANTS

MATERIAL

According to EBCS-2 1995, the design strength of concrete is defined by:

$f_{cd} = \frac{0.85 * f_{ck}}{\gamma_C}$ in compression, and (2.1)

$f_{ctd} = \frac{f_{ctk}}{\gamma_C}$ in tension (2.2)

where f_{ck}, f_{ctk} – are the characteristic cylinder compressive and tensile strength of concrete, respectively.

γ_c = Partial safety factor for Concrete

For class I works, γ_c =1.50,

According to EBCS-2 1995, the design strength of steel is defined by:

$f_{yd} = \frac{f_{yk}}{\gamma_S}$ (2.3)

where f_{yk} = the characteristic yield strength of reinforcing steel

γ_S = Partial safety factor for reinforcing steel

For class I works, γ_S = 1.15

- **Concrete C25**

For C25,

f_{ck} =0.8* f_{cu} =0.8*25 Mpa = 20 Mpa and

f_{ctk} = 0.21* [$(f_{ck})^{(2/3)}$] = 0.21* [$(20)^{(2/3)}$] = 1.547 Mpa.

Hence, $f_{cd} = \frac{0.85 * 20}{1.5} = 11.333$ Mpa

$$f_{ctd} = \frac{1.547}{1.5} = 1.031 \text{ Mpa}$$

For C25 the mean value of secant modulus of E_{cm} can be estimated as 29Gpa.

- **Steel S300**

For S300, f_{yk} = 300 Mpa

Hence, $f_{yd} = \frac{f_{yk}}{\gamma_S} = \frac{300 \text{ Mpa}}{1.15} = 260.870 \text{ Mpa}$

- **Steel S400**

For S400, f_{yk} = 400 Mpa

Hence, $f_{yd} = \frac{f_{yk}}{\gamma_S} = \frac{400 \text{ Mpa}}{1.15} = 347.826 \text{ Mpa}$

The mean value of modulus of elasticity E_s may be assumed as 200Gpa.

UNIT WEIGHT

According to EBCS-1, 1995:

$$\gamma_{concrete} = 25 \text{ kN/m}^3$$

$$\gamma_{precast\ block} = 14 \text{ kN/m}^3$$

$$\gamma_{Cement\ mortar} = 23 \text{ kN/m}^3$$

2.4. LOADS ON THE PRECAST BEAM

In general, to analyze and design a structure, it is necessary to have a clear picture of the nature and magnitude of the loads applied to the structures. [11] The following discussion covers the primary loads that must be considered for the precast beam and ways of describing and characterizing them. As discussed in the introduction, the stage of construction of the precast beam can be classified into two. The expected external load is calculated for both the initial and final stage of the precast beam. To check the capacity of the precast joist, the analysis and design output from software with sample manual calculation is used for the initial stage and for the final stage manual calculation according to EBCS-2, 1995 is executed.

2.4.1. Initial stage

This stage has different sub-stages, before the occupancy of the structure for the intended purpose; Erection stage, Block laying stage, and Concrete pouring stage.

2.4.1.1. Erection stage

At the erection stage of construction self-weight of the precast beam (dead load) is the only load considered, but the system has no live load. [8]

P_1 = $P_{precast}$(kN) = $0.5 * b * t * \gamma_{concrete} * s$

=0.5* 0.12 m * 0.08 m * 25 kN/m^3*0.15m

=<u>0.018 kN</u>

Design load = 1.3 * 0.018kN = <u>0.023 kN</u>

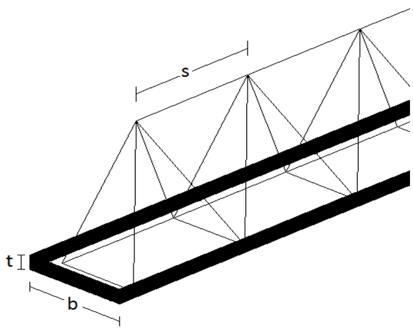

Fig.2.1. The member arrangement of the model in the initial stage

2.4.1.2. Block laying stage

In the second phase of the initial stage the self-weight of precast beam is considered as a dead load and self-weight of the ribbed block as a live load.[8]

P_1 = $P_{concrete}$(kN) = <u>0.018 kN</u>

$$A_{\text{precast block}} = 551 \text{ cm}^2$$

Refer to Appendix A.1, for the calculation of the cross-sectional area of the precast block.

P_2 = $P_{precast\ block}$(kN) = 0.5 * $A_{\text{Precast block}} * \gamma_{\text{precast block}} * s$

$$= 0.5 * 5.51 * 10^{-2}\text{m}^2 * 14 \frac{\text{kN}}{\text{m}^3} * 0.15\text{m} = \underline{0.058 \text{ kN}}$$

Construction load

$$P_2' = P_{const.\ load}' = 0.5 * q_k * b * s$$

$$= 0.5 * 0.5 \, {}^{kN}/_{m^2} * 0.6\, m * 0.15m = \underline{0.023 \text{ kN}}$$

Design load = 1.3*P_1+ 1.6*(P_2 +P_2')=1.3 * 0.018 kN + 1.6*(0.058+0.023) kN = <u>0.153 kN</u>

2.4.1.3. Concrete pouring stage

During the pouring of concrete the whole area cannot be covered once and the concrete cannot support itself. Therefore, the area covered with concrete varies with time. This vibration could also exist due to the compaction of the concrete. This implies that the load due to fresh concrete should be considered as live load. [8]

$A_{concrete} = 52800\ \mathrm{mm}^2$

Refer to Appendix A.2, for the calculation of the cross-sectional area of the concrete poured in the precast section.

$$P_3 = P_{concrete}(kN) = 0.5 * A_{concrete} * \gamma_{concrete} * s$$
$$= 0.5 * 5.28 * 10^{-2}\mathrm{m}^2 * 25\ \mathrm{kN}/_{\mathrm{m}^3} * 0.15m = \underline{0.099\mathrm{kN}}$$

Construction load

$$P_3' = P_{const.\ load}' = 0.5 * q_k * b * s$$
$$= 0.5 * 0.5\ kN/_{m^2} * 0.6\ m * 0.15m = \underline{0.023\ \mathrm{kN}}$$

<u>The system is either loaded by:</u>

- ⇨ The construction workers on the side which is not poured, i.e., equal to the block lying stage.
- ⇨ The concrete as live load on the poured side. Since the concrete will not be usable for workers before setting, the workers load (the construction load) and the fresh concrete cannot be counted as live load together.
- ⇨ The concrete part could set and the construction workers can use it as a plat form. Therefore, the construction workers as live load and the concrete as dead load is the other alternative.

Design load = $1.3*(P_1 + P_2) + 1.6*P_3$

$$= 1.3 * (0.018\mathrm{kN} + 0.059\mathrm{kN}) + 1.6 * 0.099\ \mathrm{kN} = \underline{0.259\ \mathrm{kN}}$$

Or

Design load = $1.3*(P_1+P_2+P_3) + 1.6*P_3'$

$=1.3 * (0.018kN + 0.059kN + 0.099kN) + 1.6 * 0.023kN = \underline{0.266kN}$

Among the three sub stages of the initial stage, concrete pouring stage governs. Therefore, all studies of the initial stage are done for the last sub stage.

The load combination for serviceability limit state is with a load factor of 1.0. This implies the joint load at the critical stage is:

Service load = $P_1+P_2+P_3+P_3'$

$= 0.018kN + 0.058kN + 0.099kN + 0.023kN = \underline{0.198\ kN}$

2.4.2. Final Stage

The precast joist in this thesis is designed for residential building. The final stage is after hardening of the concrete. Therefore, the precast joist is a beam with T – cross section.

*Dead Load (*Taking 30mm cement screed and 20 mm plaster)

P_4 (Cement screed) = $0.5*$ c/c spacing of the joist $* t * \Upsilon_{cement\ mortar} * S$

$= 0.5 * 0.60m * 0.03m * 23\ kN/m^3 * 0.15\ m = \underline{0.031kN}$

P_5 (Plastering) $=0.5*$ c/c spacing of the joist $* t * \Upsilon_{cement\ mortar} * S$

$=0.5 * 0.60m * 0.02m * 23\ kN/m^3 * 0.15 = \underline{0.021\ kN}$

$P = P_1 + P_2 + P_3 + P_4 + P_5$

$= 0.018\ kN + 0.058\ kN + 0.099\ kN + 0.031\ kN + 0.021\ kN = \underline{0.230\ kN}$

Live Load: according to EBCS - 1 - 1995 Table 2.10., for residential areas q_k = <u>2.0 kN/m^2</u>

This implies joint load due to live load = 0.5 * (2 kN/m^2 * 0.6m * 0.15m) = <u>0.090kN</u>

Design Load: $P_d = 1.3* G_k + 1.6*Q_k$ = 1.3*(0.230 kN) + 1.6*(0.090 kN) = <u>0.443kN</u>

Table 2.1. Load history of the precast joist

Equivalent Load that acts on the precast joist	INITIAL STAGE			FINAL STAGE
	Precast only	Block laying stage	Concrete pouring stage	
Joint Load at each joint (kN)	**0.023**	**0.153**	**0.266**	0.443
Uniform line load (kN/m)	0.307	2.04	3.55	**5.907**

The joint load acts at the joint as shown in the Fig.4.1 and the line load acts on the center line of the section. The conversion factor between the joint load and the line load is 0.075, which is equal to s/2. As shown in the Fig.2.1, s is the spacing between two consecutive joints and the value 2 implies the number of joints on the bottom part of the system in the initial stage, which has the same coordinate along an axis parallel to the longitudinal reinforcement. As stated above for the initial stage the 3rd phase is with higher value and therefore it governs.

3. ANALYSIS AND DESIGN PRECAST BEAM ELEMENT

The study of the analysis and design of the precast joist includes both the ultimate limit state and serviceability limit state conditions; in both cases it covers the initial stage and final stage of construction of the precast joist.

3.1. INITIAL STAGE

In the initial stage one hundred twenty eight models have been prepared to study the behavior of the precast joist.

3.1.1. Ultimate limit state

The design joint load in the initial stage is 0.266 kN and the study on the One hundred twenty eight models has been done with a joint load of 0.275 kN. The ultimate limit state of the system is checked by calculating the maximum joint load and from the models, it is observed that the failure of the system occurs due to different reasons. The demand to capacity ratio of critical members of all models is summarized in the 0. The values are obtained from the structural software ETABS Nonlinear V.9.7.4.

The first column groups the models that have the same size and arrangement of longitudinal reinforcement. In each group, there are eight models that can again be grouped into four depending on the number of temporary intermediate supports. The difference between the two models in each sub-group is the size of stirrups. For instance, the first model in group one has no temporary intermediate support, and it is with 1Φ8 for top reinforcement, 2Φ8 for bottom reinforcement, and Φ6 c/c 150 for stirrup, and it has a demand to capacity ratio of 5.287, 1.464 and 3.630, respectively.

Table 3.1. The demand to capacity ratio of the critical members of different models

Group	Position	Reinforcement	Number of temporary intermediate support							
			0		1		2		3	
			X=6	X=8	X=6	X=8	X=6	X=8	X=6	X=8
1	Top reinforcement	1Φ8	5.287	5.305	0.855	0.842	0.387	0.384	0.212	0.207
	Bottom reinforcement	2Φ8	1.464	1.468	0.596	0.592	0.213	0.204	0.119	0.115
	Stirrups	ΦX c/c 150	3.630	1.226	2.172	0.756	1.328	0.461	0.948	0.331
2	Top reinforcement	1Φ8	5.288	5.305	0.860	0.845	0.389	0.384	0.213	0.208
	Bottom reinforcement	2Φ10	0.957	0.960	0.363	0.343	0.140	0.125	0.083	0.073
	Stirrups	ΦX c/c 150	3.639	1.229	2.152	0.753	1.316	0.458	0.937	0.329
3	Top reinforcement	1Φ8	5.290	5.308	0.863	0.847	0.390	0.385	0.214	0.209
	Bottom reinforcement	2Φ12	0.685	0.686	0.274	0.244	0.114	0.094	0.072	0.058
	Stirrups	ΦX c/c 150	3.644	1.231	2.121	0.747	1.298	0.454	0.923	0.326
4	Top reinforcement	1Φ8	5.294	5.312	0.865	0.849	0.390	0.386	0.214	0.209
	Bottom reinforcement	2Φ14	0.524	0.524	0.235	0.197	0.105	0.081	0.069	0.052
	Stirrups	ΦX c/c 150	3.648	1.233	2.075	0.738	1.271	0.449	0.901	0.321

X – is the diameter of the stirrups with spacing of 150mm

Table 3.1. The demand to capacity ratio of the critical members of different models (Continued)

Group	Position	Reinforcement	Number of temporary intermediate support							
			0		1		2		3	
			X=6	X=8	X=6	X=8	X=6	X=8	X=6	X=8
5	Top reinforcement	1Φ10	2.783	2.792	0.457	0.453	0.207	0.204	0.114	0.111
	Bottom reinforcement	2Φ8	1.455	1.459	0.582	0.582	0.208	0.201	0.114	0.111
	Stirrups	ΦX c/c 150	3.641	1.227	2.171	0.757	1.322	0.462	0.943	0.331
6	Top reinforcement	1Φ10	2.780	2.789	0.460	0.449	0.208	0.204	0.115	0.112
	Bottom reinforcement	2Φ10	0.946	0.948	0.351	0.334	0.136	0.122	0.080	0.070
	Stirrups	ΦX c/c 150	3.651	1.230	2.148	0.751	1.310	0.459	0.932	0.328
7	Top reinforcement	1Φ10	2.780	2.789	0.463	0.451	0.209	0.205	0.116	0.112
	Bottom reinforcement	2Φ12	0.671	0.672	0.263	0.236	0.111	0.092	0.069	0.055
	Stirrups	ΦX c/c 150	3.657	1.233	2.115	0.744	1.291	0.455	0.916	0.325
8	Top reinforcement	1Φ10	2.781	2.790	0.465	0.452	0.209	0.205	0.116	0.112
	Bottom reinforcement	2Φ14	0.507	0.508	0.225	0.189	0.101	0.078	0.066	0.050
	Stirrups	ΦX c/c 150	3.661	1.234	2.069	0.734	1.264	0.449	0.895	0.320

X – is the diameter of the stirrups with spacing of 150mm

Table 3.1. The demand to capacity ratio of the critical members of different models (Continued)

Group	Position	Reinforcement	Number of temporary intermediate support							
			0		1		2		3	
			X=6	X=8	X=6	X=8	X=6	X=8	X=6	X=8
9	Top reinforcement	1Φ12	1.736	1.741	0.323	0.322	0.131	0.128	0.073	0.070
	Bottom reinforcement	2Φ8	1.451	1.455	0.570	0.575	0.204	0.199	0.111	0.108
	Stirrups	ΦX c/c 150	3.648	1.228	2.161	0.757	1.319	0.462	0.939	0.331
10	Top reinforcement	1Φ12	1.730	1.735	0.314	0.316	0.132	0.128	0.074	0.071
	Bottom reinforcement	2Φ10	0.940	0.942	0.341	0.328	0.133	0.120	0.078	0.068
	Stirrups	ΦX c/c 150	3.659	1.232	2.137	0.751	1.305	0.459	0.926	0.328
11	Top reinforcement	1Φ12	1.729	1.733	0.307	0.312	0.133	0.129	0.074	0.071
	Bottom reinforcement	2Φ12	0.664	0.665	0.255	0.230	0.108	0.090	0.067	0.054
	Stirrups	ΦX c/c 150	3.665	1.234	2.104	0.744	1.286	0.455	0.910	0.324
12	Top reinforcement	1Φ12	1.729	1.733	0.302	0.308	0.133	0.129	0.074	0.071
	Bottom reinforcement	2Φ14	0.499	0.499	0.217	0.184	0.098	0.076	0.064	0.048
	Stirrups	ΦX c/c 150	3.670	1.236	2.057	0.734	1.258	0.449	0.888	0.319

X – is the diameter of the stirrups with spacing of 150mm

Table 3.1. The demand to capacity ratio of the critical members of different models (Continued)

Group	Position	Reinforcement	Number of temporary intermediate support							
			0		1		2		3	
			X=6	X=8	X=6	X=8	X=6	X=8	X=6	X=8
13	Top reinforcement	1Φ14	1.200	1.203	0.251	0.246	0.097	0.092	0.057	0.054
	Bottom reinforcement	2Φ8	1.448	1.453	0.561	0.569	0.201	0.197	0.110	0.106
	Stirrups	ΦX c/c 150	3.654	1.230	2.157	0.756	1.318	0.463	0.936	0.330
14	Top reinforcement	1Φ14	1.193	1.196	0.242	0.239	0.094	0.090	0.056	0.052
	Bottom reinforcement	2Φ10	0.937	0.939	0.333	0.323	0.130	0.118	0.077	0.066
	Stirrups	ΦX c/c 150	3.665	1.233	2.129	0.750	1.303	0.459	0.922	0.327
15	Top reinforcement	1Φ14	1.190	1.193	0.235	0.235	0.094	0.090	0.055	0.051
	Bottom reinforcement	2Φ12	0.660	0.661	0.248	0.225	0.105	0.088	0.066	0.052
	Stirrups	ΦX c/c 150	3.671	1.235	2.093	0.742	1.282	0.455	0.905	0.323
16	Top reinforcement	1Φ14	1.189	1.192	0.230	0.231	0.094	0.090	0.054	0.050
	Bottom reinforcement	2Φ14	0.493	0.494	0.210	0.179	0.096	0.075	0.063	0.047
	Stirrups	ΦX c/c 150	3.677	1.237	2.045	0.732	1.254	0.449	0.883	0.318

X – is the diameter of the stirrups with spacing of 150mm

The demand to capacity ratio is the ratio of the internal force due to the external load and the load carrying capacity of the section.

In the initial stage the demand to capacity ratio of the members depend on:

- The external load, since it affects the magnitude of internal member force.
- The number of temporary intermediate supports provided to the precast system, since it affects the magnitude of internal member force.
- The cross sectional size of the member, since it affects the Cross-section capacity of the member.

To satisfy the Ultimate Limit State requirement, the demand to capacity ratio should be less than one. Therefore, from the result in the above Table 3.1, one temporary intermediate support is required if the stirrup arrangement is ϕ8 c/c 150, but the minimum number intermediate support increases to three, if the shear reinforcement is ϕ6 c/c 150.

3.1.2. Serviceability limit state

According to EBCS-2, 1995, section 5.2.2 the limiting values is specified as:

i. The final deflection (including the effect of temperature, creep and shrinkage) of all horizontal members shall not, in general, exceed the value

$$\delta = \frac{L_e}{200} \qquad (3.4)$$

where L_e = the effective span

ii. For roof or floor construction supporting or attached to non-structural elements (e.g. partitions and finishes) likely to be damaged by large deflection, that part of the deflection which occurs after the attachment of the non-structural elements shall not exceed the value:

$$\delta = \frac{L_e}{350} \leq 20mm \qquad (3.5)$$

Table 3.2. The deflection limit of precast joist for different number of temporary intermediate support

No. of temporary intermediate supports	Effective length (mm.)	Deflection limit (mm.)	
		$\delta = \frac{L_e}{200}$	$\delta = \frac{L_e}{350}$
0	5000.000	25.000	14.286
1	2500.000	12.500	7.143
2	1666.667	8.333	4.762
3	1250.000	6.250	3.571

Table 3.3. Deflection of all models for different number of temporary intermediate supports

Model	Longitudinal reinforcement		Stirrup	Maximum deflection (mm.)			
	Top	Bottom		n = 0	n = 1	n = 2	n = 3
1	1Φ8	1Φ8	Φ6 c/c 150	68.60	3.20	0.90	0.40
2	1Φ8	1Φ8	Φ8 c/c 150	67.20	2.70	0.70	0.20
3	1Φ8	1Φ10	Φ6 c/c 150	60.80	2.90	0.80	0.40
4	1Φ8	1Φ10	Φ8 c/c 150	59.40	2.50	0.60	0.40
5	1Φ8	1Φ12	Φ6 c/c 150	56.70	2.80	0.80	0.40
6	1Φ8	1Φ12	Φ8 c/c 150	55.20	2.30	0.60	0.20
7	1Φ8	1Φ14	Φ6 c/c 150	54.20	2.70	0.80	0.30
8	1Φ8	1Φ14	Φ8 c/c 150	52.70	2.20	0.60	0.20
9	1Φ10	1Φ8	Φ6 c/c 150	53.00	2.70	0.80	0.30
10	1Φ10	1Φ8	Φ8 c/c 150	51.60	2.20	0.60	0.20
11	1Φ10	1Φ10	Φ6 c/c 150	45.30	2.40	0.70	0.30
12	1Φ10	1Φ10	Φ8 c/c 150	43.80	2.00	0.50	0.30
13	1Φ10	1Φ12	Φ6 c/c 150	41.10	2.30	0.30	0.70
14	1Φ10	1Φ12	Φ8 c/c 150	39.60	1.80	0.50	0.20
15	1Φ10	1Φ14	Φ6 c/c 150	38.60	2.20	0.70	0.30
16	1Φ10	1Φ14	Φ8 c/c 150	37.10	1.70	0.50	0.20
17	1Φ12	1Φ8	Φ6 c/c 150	44.60	2.40	0.70	0.30
18	1Φ12	1Φ8	Φ8 c/c 150	43.10	1.90	0.50	0.20
19	1Φ12	1Φ10	Φ6 c/c 150	36.80	2.20	0.60	0.30
20	1Φ12	1Φ10	Φ8 c/c 150	35.30	1.70	0.50	0.30

Table 3.3. Deflection of all models for different number of temporary intermediate supports (Continued)

Model	Longitudinal reinforcement		Stirrup	Maximum deflection (mm.)			
	Top	Bottom		n = 0	n = 1	n = 2	n = 3
21	1Φ12	1Φ12	Φ6 c/c 150	32.70	2.00	0.60	0.30
22	1Φ12	1Φ12	Φ8 c/c 150	31.10	1.60	0.40	0.20
23	1Φ12	1Φ14	Φ6 c/c 150	30.10	2.00	0.60	0.30
24	1Φ12	1Φ14	Φ8 c/c 150	28.60	1.50	0.40	0.20
25	1Φ14	1Φ8	Φ6 c/c 150	39.50	2.30	0.70	0.30
26	1Φ14	1Φ8	Φ8 c/c 150	38.00	1.80	0.50	0.20
27	1Φ14	1Φ10	Φ6 c/c 150	31.80	2.00	0.60	0.30
28	1Φ14	1Φ10	Φ8 c/c 150	30.20	1.50	0.40	0.30
29	1Φ14	1Φ12	Φ6 c/c 150	27.60	1.90	0.60	0.30
30	1Φ14	1Φ12	Φ8 c/c 150	26.00	1.40	0.40	0.20
31	1Φ14	1Φ14	Φ6 c/c 150	25.00	1.80	0.60	0.30
32	1Φ14	1Φ14	Φ8 c/c 150	23.50	1.30	0.40	0.20

n – The number of temporary intermediate supports.

By comparing the values of the above tables, Table 3.2 and Table 3.3 for all models, at least one temporary intermediate support is required to satisfy the serviceability limit state requirement.

3.2. FINAL STAGE

The purpose of this thesis is to determine the appropriate size and arrangement of longitudinal reinforcement and stirrup of the precast joist. For this purpose, the ultimate limit state of the system is checked by comparing the maximum flexural and shear resistance of the section with the flexural and shear capacity of the section, respectively. The design uniform line load in the final stage is 5.907 kN/m.

In the initial stage the precast joist is modeled as a simply supported system. Similarly, the final section is also modeled as simply supported beam to consider the maximum effect. In the final stage the maximum positive moment occurs if the slab system is one span, in the direction parallel to the precast joist. After placement of the ribbed blocks on the precast joist, additional negative reinforcement should be provided before pouring the concrete, if the system is continuous.

3.2.1. Ultimate limit state

In the final stage the failure condition of the members depends on:

- The external load, since it affects the magnitude of internal force of the cross-section.
- The cross sectional size of the member, since it affects the cross-section capacity of the member.

3.2.1.1. Flexural capacity

The maximum span moment induced in the final stage can be calculated by using elastic analysis, $M = \frac{w*L^2}{8}$, by assuming a simply supported one span section, where the uniform line load that acts in the final stage is 5.907 kN/m as specified in section 2.4., Table 2.1.

Therefore, $M_{max} = \frac{5.907\ kN/m * 5^2}{8} = 18.460\ kNm$ and the maximum moment resistance of the precast system is calculated according to EBCS-2, 1995.

The maximum moment resistance of the precast system is shown in Table 5.4 and sample calculation is done for a single case in the design example i.e. in section 4.2.1.1.

3.2.1.2. Shear capacity

The ultimate limit state resistance of the section for shear is determined, according to EBCS-2, 1995 section 4.5. The table below gives the maximum line load the final section can carry and the calculation is shown in Appendix B.

Table 3.4. Shear capacity of the section of all models

Reinforcement Size	Maximum line load capacity of the section (kN/m)
Φ6 c/c 150	14.42
Φ8 c/c 150	21.96

3.2.2. Serviceability limit state

According to EBCS-2, 1995 sec. 5.2.3, the minimum effective depth obtained from equation 3.6 shown below shall be provided unless computation of deflection indicates that smaller thickness may be used without exceeding the limits:

$$d = \left[0.4 + 0.6 * \frac{f_{yk}}{400}\right] * \frac{L_e}{\beta_a} \qquad (3.6)$$

f_{yk} in Mpa

β_a – is a constant value for different structural member and support condition

L_e – is the effective length

For S – 400, effective length of 5000mm, β_a=24 for the end span

$$d = \left[0.4 + 0.6 * \frac{400}{400}\right] * \frac{5000mm}{24} = 208.33mm$$

4. DESIGN EXAMPLE

The design example is on the economical section, for the residential building. To select the model type which is safe and economical, refer to the Table 3.1 in the third chapter. The economical precast joist element, with respect to the minimum usage of reinforcement, has longitudinal reinforcement of 1ϕ8 and 2ϕ12 for the top and bottom reinforcement respectively; and ϕ6 c/c 150 for stirrup.

The purpose of this section is not only to show how to design the economical section but also to show how any of the models discussed can be designed.

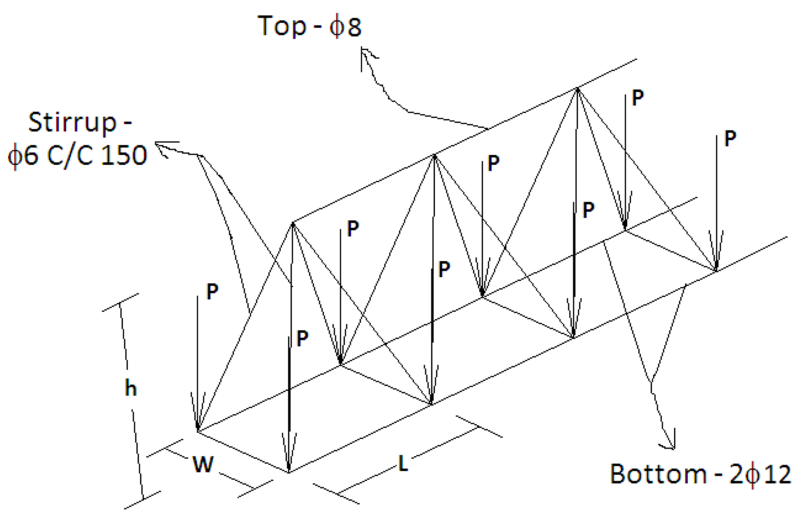

Fig.4.1. The model in the initial stage with the point load at the joint

4.1. INITIAL STAGE

During modeling and analysis in the initial stage, the system is loaded with a joint load (P) that has gradually increased to get the load that causes failure. After having the failure load from the analysis, it is compared with the load at different stage with the actual load that acts on the section to check whether the system is safe or not. The actual load is calculated and summarized in Table 2.1 of section 2.3. In the initial stage temporary intermediate support can be provided if the system is not safe either for the ultimate limit analysis or for the serviceability limit analysis.

4.1.1. Ultimate limit state

The joint load on the model shown in the Fig.4.1 above is gradually increased up to the failure of one or more members for different number of temporary intermediate support condition. Currently, the practice in most of the sites of Addis Ababa is to support at two or three intermediate points for the precast beam during construction in the initial stage without clear demarcation.

The following discussion on the above precast joist is for different temporary intermediate support condition without external formwork, i.e.

- Without temporary intermediate support.
- With one temporary intermediate support
- With two temporary intermediate supports
- With three temporary intermediate supports

The table below shows the summary of the demand to capacity ratio of the top reinforcement, stirrup, and bottom reinforcement of the critical members.

Table 4.1. Demand to capacity ratio of the economical section for different joint load

Joint load (kN)	Position of reinforcement	Number of intermediate support			
		0	1	2	3
0.025	**Top reinforcement**	**0.530**	0.086	0.039	0.021
	Bottom reinforcement	0.069	0.028	0.012	0.007
	Stirrups	0.359	0.213	0.131	0.093
0.05	**Top reinforcement**	**1.006**	0.164	0.074	0.040
	Bottom reinforcement	0.130	0.052	0.022	0.014
	Stirrups	0.679	0.404	0.247	0.176
0.075	Top reinforcement	1.482	0.242	0.109	0.060
	Bottom reinforcement	0.192	0.077	0.032	0.020
	Stirrups	0.996	0.595	0.364	0.259
0.1	Top reinforcement	1.958	0.319	0.144	0.079
	Bottom reinforcement	0.254	0.102	0.042	0.027
	Stirrups	1.313	0.786	0.481	0.342
0.125	Top reinforcement		0.397	0.179	0.098
	Bottom reinforcement		0.126	0.053	0.033
	Stirrups		**0.977**	0.598	0.425
0.15	Top reinforcement		0.475	0.214	0.118
	Bottom reinforcement		0.151	0.063	0.040
	Stirrups		**1.167**	0.715	0.508
0.175	Top reinforcement		0.552	0.249	0.137
	Bottom reinforcement		0.176	0.073	0.046
	Stirrups		1.358	0.831	0.591
0.2	Top reinforcement		0.630	0.284	0.156
	Bottom reinforcement		0.200	0.084	0.053
	Stirrups		1.549	**0.948**	0.674

Table 4.1. Demand to capacity ratio of the economical section for different joint load (Continued)

Joint load (kN)	Position of reinforcement	Number of intermediate support			
		0	1	2	3
0.225	Top reinforcement			0.319	0.175
	Bottom reinforcement			0.094	0.059
	Stirrups			**1.065**	0.757
0.25	Top reinforcement			0.354	0.195
	Bottom reinforcement			0.104	0.066
	Stirrups			1.181	0.840
0.275	Top reinforcement			0.390	0.214
	Bottom reinforcement			0.114	0.072
	Stirrups			1.298	**0.923**
0.3	Top reinforcement			0.425	0.233
	Bottom reinforcement			0.125	0.079
	Stirrups			1.415	**1.006**
0.325	Top reinforcement				0.253
	Bottom reinforcement				0.085
	Stirrups				1.089
0.35	Top reinforcement				0.272
	Bottom reinforcement				0.092
	Stirrups				1.171
0.375	Top reinforcement				0.291
	Bottom reinforcement				0.098
	Stirrups				1.254
0.4	Top reinforcement				0.310
	Bottom reinforcement				0.105
	Stirrups				1.337

Failure conditions from Table 4.1 can be summarized as shown below.

1. When there is no temporary intermediate support

Failure load: between 0.025kN and 0.050kN

Failure mode: “buckling of top reinforcement.”

The system fails in the initial stage (block laying stage)

To have a safe structural system we can propose different options;

- To increase the size of the longitudinal reinforcement and the stirrups
- To adjust the spacing of the diagonal members (the stirrups)
- To modify the geometry of the model (the height, the width or the length of the model)

Since the decision should consider the effect in the final stage. The effect of the provision of temporary intermediate support is treated for the above selected model as follows.

2. When there is one temporary intermediate support

Failure load: between 0.125kN and 0.150kN

Failure mode: “buckling of stirrup.”

The system fails in the initial stage (block laying stage)

3. When there are two temporary intermediate support

Failure load: between 0.200kN and 0.225kN

Failure mode: “buckling of stirrup.”

The system fails in the initial stage (concrete pouring stage)

4. When there are three temporary intermediate support

Failure load: between 0.2750kN and 0.300kN

Failure mode: “buckling of stirrup.”

The system is safe against the maximum expected load.

The design load at each joint after pouring of concrete in the initial stage is 0.266kN; this implies the system will be safe when three temporary intermediate supports are provided. Therefore, at least three temporary intermediate supports should be provided in the initial stage to satisfy the ultimate limit state requirement.

The following section covers the discussion about the position and type of member that fails for different loading conditions of the members. Each section discusses about the same precast joist for different number of intermediate support.

4.1.1.1. When there is no temporary intermediate support

The critical members for this case are the longitudinal bars in the top reinforcement. Therefore, the discussion in this section covers the members of the top reinforcement.

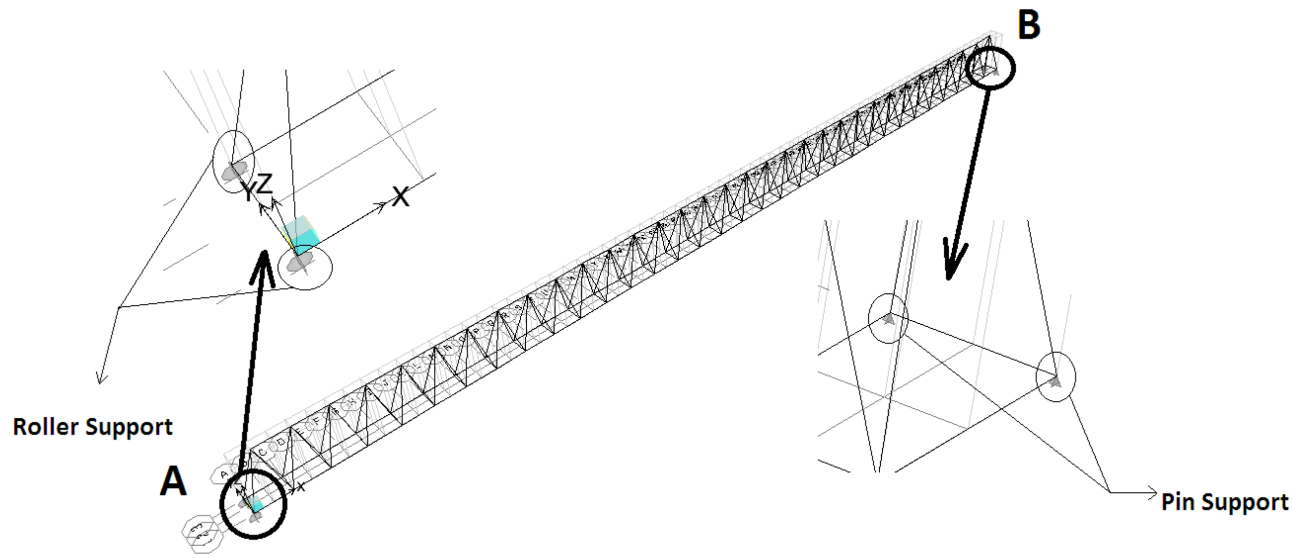

Fig.4.2. Precast joist only supported at the ends by the Girder

To study the step wise failure mechanism of the members of the above precast beam model, the demand to capacity ratio of all the top reinforcement members are checked. The Table 4.2 shown below gives the demand to capacity ratio of the above model for different joint load.

In the Table 4.2 the label of the members cannot be identified. The purpose of the table is to show the variation of the D-C ratio of all the members of the top reinforcement.

The first compression members that fail are located at the midpoint of the precast system. And when the load increases, in a symmetrical manner the members to the left and the right of the midpoint starts to fail. This idea is by assuming the members that fail will stay in position after failure, by increasing the size of the failed members.

The following table shows the demand to capacity ratio of the top reinforcement of the above model, without temporary intermediate support, for different joint load. And the last column of the table gives the type of internal axial force in the member, i.e., either compression (C) or tension (T).

Table 4.2. Demand to capacity ratio of the top reinforcement of the economical section when there is no temporary intermediate support.

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load				Axial Load
		0.025kN	0.050kN	0.075kN	0.100kN	
B17 And B18	8	0.530	1.006	1.482	1.958	C
B16 And B19	8	0.526	0.999	1.472	1.945	C
B15 And B20	8	0.519	0.985	1.451	1.917	C
B14 And B21	8	0.507	0.963	1.419	1.875	C
B13 And B22	8	0.492	0.934	1.377	1.819	C
B12 And B23	8	0.473	0.898	1.323	1.748	C
B11 And B24	8	0.450	0.854	1.258	1.661	C
B10 And B25	8	0.423	0.802	1.181	1.560	C
B9 And B26	8	0.392	0.744	1.095	1.446	C
B8 And B27	8	0.357	0.678	0.998	1.318	C
B7 And B28	8	0.318	0.604	0.890	1.175	C
B6 And B29	8	0.276	0.524	0.771	1.018	C
B5 And B17	8	0.229	0.435	0.641	0.847	C
B4 And B31	8	0.179	0.340	0.501	0.661	C
B3 And B32	8	0.125	0.237	0.349	0.461	C
B2 And B33	8	0.069	0.131	0.193	0.254	C

4.1.1.2. When there is one temporary intermediate support

The critical members are stirrups if one temporary intermediate support is provided. Therefore, the discussion in this section covers the members of the stirrup.

Similar to the model without support, to study the step wise failure mechanism of the members of the precast joist with one temporary intermediate support, the comparison of the demand to capacity ratio of the entire members is done.

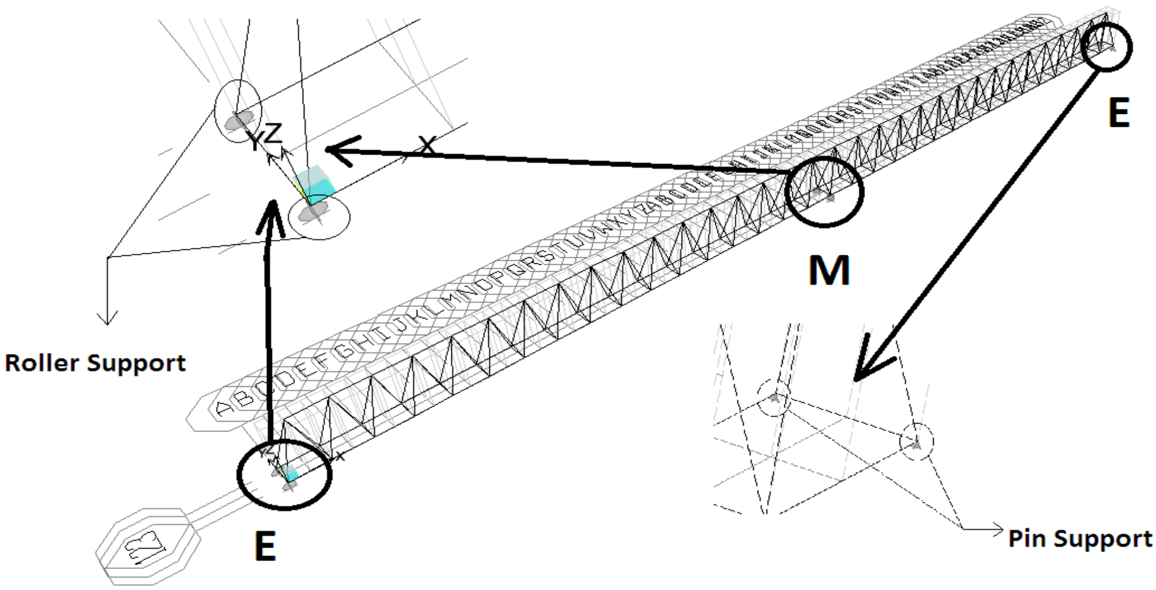

Fig.4.3. Precast joist supported at the ends by the Girder and with one temporary intermediate support

The first members that fail are members under compression and then members under tension. In addition, all the members in the system fail in a symmetrical manner.

The first compression members that fail are located at the middle support which goes to the left and right of the middle support (M). As the load increases gradually the member failure goes to the compression members around the end support (E), then the members around the end and the middle support will fail alternatively as shown in Table 4.3.

The tension members at the support starts to fail and it goes in the same manner. Again the remaining compression members and tension members will fail. This idea is by assuming the members that fail will stay in position after failure by increasing the size of the failed members.

The following Table 4.3[2] shows the demand to capacity ratio of the members of the above model, with one temporary intermediate support, for different joint load. It includes the position of the member which fails, either near to the end support (E) or near to the Middle Support (M) on the second column and the last column gives the type of internal axial force in the member, i.e., either compression (C) or tension (T).

[2] The purpose of the table is to show the variation of the demand to capacity ratio of the members, and it is analysis output from ETABS Nonlinear V.9.7.4.

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support

Label of member	Member position	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
			0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D34	M	6	0.213	0.404	0.595	0.786	0.977	1.167	1.358	1.549	C
D303	M	6	0.213	0.404	0.595	0.786	0.977	1.167	1.358	1.549	C
D35	M	6	0.205	0.388	0.571	0.754	0.938	1.121	1.304	1.487	C
D304	M	6	0.205	0.388	0.571	0.754	0.938	1.121	1.304	1.487	C
D32	M	6	0.200	0.379	0.557	0.734	0.910	1.086	1.261	1.438	C
D301	M	6	0.200	0.379	0.557	0.734	0.910	1.086	1.261	1.438	C
D37	M	6	0.192	0.363	0.533	0.703	0.872	1.039	1.207	1.374	C
D306	M	6	0.192	0.363	0.533	0.703	0.872	1.039	1.207	1.374	C
D30	M	6	0.176	0.333	0.489	0.645	0.800	0.955	1.109	1.263	C
D299	M	6	0.176	0.333	0.489	0.645	0.800	0.955	1.109	1.263	C
D39	M	6	0.167	0.316	0.465	0.613	0.761	0.908	1.055	1.202	C
D308	M	6	0.167	0.316	0.465	0.613	0.761	0.908	1.055	1.202	C
D28	M	6	0.154	0.292	0.429	0.565	0.701	0.837	0.972	1.107	C
D297	M	6	0.154	0.292	0.429	0.565	0.701	0.837	0.972	1.107	C
D41	M	6	0.145	0.275	0.405	0.534	0.662	0.790	0.918	1.046	C
D310	M	6	0.145	0.275	0.405	0.534	0.662	0.790	0.918	1.046	C
D1	E	6	0.139	0.263	0.386	0.509	0.632	0.755	0.877	0.999	C
D135	E	6	0.139	0.263	0.386	0.509	0.632	0.755	0.877	0.999	C
D26	M	6	0.132	0.249	0.366	0.483	0.599	0.716	0.831	0.947	C
D295	M	6	0.132	0.249	0.366	0.483	0.599	0.716	0.831	0.947	C
D66	E	6	0.125	0.237	0.348	0.459	0.570	0.680	0.791	0.901	C
D335	E	6	0.125	0.237	0.348	0.459	0.570	0.680	0.791	0.901	C

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D43	6	0.123	0.233	0.342	0.451	0.560	0.669	0.777	0.885	C
D312	6	0.123	0.233	0.342	0.451	0.560	0.669	0.777	0.885	C
D3	6	0.116	0.221	0.324	0.428	0.531	0.634	0.736	0.839	C
D272	6	0.116	0.221	0.324	0.428	0.531	0.634	0.736	0.839	C
D24	6	0.109	0.207	0.304	0.401	0.498	0.594	0.691	0.787	C
D293	6	0.109	0.207	0.304	0.401	0.498	0.594	0.691	0.787	C
D64	6	0.103	0.194	0.286	0.377	0.468	0.559	0.650	0.740	C
D333	6	0.103	0.194	0.286	0.377	0.468	0.559	0.650	0.740	C
D45	6	0.101	0.190	0.280	0.369	0.459	0.547	0.636	0.725	C
D314	6	0.101	0.190	0.280	0.369	0.459	0.547	0.636	0.725	C
D5	6	0.094	0.178	0.262	0.346	0.429	0.513	0.596	0.679	C
D274	6	0.094	0.178	0.262	0.346	0.429	0.513	0.596	0.679	C
D22	6	0.087	0.164	0.242	0.319	0.396	0.473	0.550	0.626	C
D291	6	0.087	0.164	0.242	0.319	0.396	0.473	0.550	0.626	C
D62	6	0.080	0.152	0.224	0.295	0.366	0.437	0.508	0.579	C
D331	6	0.080	0.152	0.224	0.295	0.366	0.437	0.508	0.579	C
D47	6	0.078	0.148	0.218	0.287	0.356	0.426	0.495	0.564	C
D316	6	0.078	0.148	0.218	0.287	0.356	0.426	0.495	0.564	C
D7	6	0.072	0.136	0.200	0.263	0.327	0.391	0.454	0.517	C
D276	6	0.072	0.136	0.200	0.263	0.327	0.391	0.454	0.517	C
D20	6	0.064	0.122	0.179	0.237	0.294	0.351	0.408	0.465	C

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D289	6	0.064	0.122	0.179	0.237	0.294	0.351	0.408	0.465	C
D60	6	0.058	0.110	0.161	0.213	0.264	0.315	0.367	0.418	C
D329	6	0.058	0.110	0.161	0.213	0.264	0.315	0.367	0.418	C
D49	6	0.056	0.105	0.155	0.205	0.254	0.304	0.353	0.402	C
D318	6	0.056	0.105	0.155	0.205	0.254	0.304	0.353	0.402	C
D9	6	0.049	0.093	0.137	0.181	0.225	0.269	0.312	0.356	C
D278	6	0.049	0.093	0.137	0.181	0.225	0.269	0.312	0.356	C
D18	6	0.042	0.079	0.117	0.154	0.191	0.229	0.266	0.303	C
D287	6	0.042	0.079	0.117	0.154	0.191	0.229	0.266	0.303	C
D33	6	0.036	0.068	0.100	0.132	0.164	0.196	0.229	0.261	T
D302	6	0.036	0.068	0.100	0.132	0.164	0.196	0.229	0.261	T
D58	6	0.035	0.067	0.099	0.130	0.161	0.193	0.224	0.256	C
D327	6	0.035	0.067	0.099	0.130	0.161	0.193	0.224	0.256	C
D36	6	0.035	0.065	0.096	0.127	0.158	0.189	0.220	0.250	T
D305	6	0.035	0.065	0.096	0.127	0.158	0.189	0.220	0.250	T
D51	6	0.033	0.063	0.093	0.122	0.152	0.181	0.211	0.240	C
D320	6	0.033	0.063	0.093	0.122	0.152	0.181	0.211	0.240	C
D31	6	0.033	0.062	0.092	0.121	0.150	0.180	0.209	0.238	T
D300	6	0.033	0.062	0.092	0.121	0.150	0.180	0.209	0.238	T
D38	6	0.031	0.060	0.088	0.116	0.144	0.172	0.200	0.228	T
D307	6	0.031	0.060	0.088	0.116	0.144	0.172	0.200	0.228	T

Table 4.3. The Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D29	6	0.029	0.055	0.081	0.106	0.132	0.158	0.184	0.210	T
D298	6	0.029	0.055	0.081	0.106	0.132	0.158	0.184	0.210	T
D40	6	0.028	0.052	0.077	0.101	0.126	0.150	0.175	0.199	T
D309	6	0.028	0.052	0.077	0.101	0.126	0.150	0.175	0.199	T
D11	6	0.027	0.051	0.075	0.098	0.122	0.146	0.170	0.193	C
D280	6	0.027	0.051	0.075	0.098	0.122	0.146	0.170	0.193	C
D27	6	0.025	0.048	0.070	0.093	0.115	0.137	0.160	0.182	T
D296	6	0.025	0.048	0.070	0.093	0.115	0.137	0.160	0.182	T
D42	6	0.024	0.045	0.066	0.087	0.109	0.130	0.151	0.172	T
D311	6	0.024	0.045	0.066	0.087	0.109	0.130	0.151	0.172	T
D2	6	0.022	0.042	0.062	0.082	0.102	0.122	0.142	0.162	T
D136	6	0.022	0.042	0.062	0.082	0.102	0.122	0.142	0.162	T
D25	6	0.021	0.040	0.060	0.079	0.098	0.117	0.136	0.155	T
D294	6	0.021	0.040	0.060	0.079	0.098	0.117	0.136	0.155	T
D65	6	0.020	0.038	0.056	0.074	0.092	0.110	0.127	0.145	T
D334	6	0.020	0.038	0.056	0.074	0.092	0.110	0.127	0.145	T
D44	6	0.020	0.038	0.056	0.073	0.091	0.109	0.127	0.145	T
D313	6	0.020	0.038	0.056	0.073	0.091	0.109	0.127	0.145	T
D16	6	0.020	0.037	0.054	0.071	0.089	0.106	0.123	0.140	C
D285	6	0.020	0.037	0.054	0.071	0.089	0.106	0.123	0.140	C
D4	6	0.019	0.036	0.053	0.069	0.086	0.103	0.120	0.137	T

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D273	6	0.019	0.036	0.053	0.069	0.086	0.103	0.120	0.137	T
D23	6	0.018	0.033	0.049	0.065	0.080	0.096	0.112	0.127	T
D292	6	0.018	0.033	0.049	0.065	0.080	0.096	0.112	0.127	T
D63	6	0.017	0.032	0.046	0.061	0.076	0.091	0.106	0.120	T
D332	6	0.017	0.032	0.046	0.061	0.076	0.091	0.106	0.120	T
D46	6	0.016	0.031	0.045	0.060	0.074	0.088	0.103	0.117	T
D315	6	0.016	0.031	0.045	0.060	0.074	0.088	0.103	0.117	T
D6	6	0.015	0.029	0.042	0.055	0.069	0.082	0.096	0.109	T
D275	6	0.015	0.029	0.042	0.055	0.069	0.082	0.096	0.109	T
D21	6	0.014	0.026	0.039	0.051	0.063	0.076	0.088	0.100	T
D290	6	0.014	0.026	0.039	0.051	0.063	0.076	0.088	0.100	T
D56	6	0.013	0.024	0.036	0.047	0.059	0.070	0.081	0.093	C
D61	6	0.013	0.024	0.036	0.047	0.059	0.070	0.081	0.093	T
D325	6	0.013	0.024	0.036	0.047	0.059	0.070	0.081	0.093	C
D330	6	0.013	0.024	0.036	0.047	0.059	0.070	0.081	0.093	T
D48	6	0.013	0.024	0.035	0.046	0.057	0.068	0.079	0.090	T
D317	6	0.013	0.024	0.035	0.046	0.057	0.068	0.079	0.090	T
D8	6	0.011	0.022	0.032	0.042	0.052	0.062	0.072	0.082	T
D277	6	0.011	0.022	0.032	0.042	0.052	0.062	0.072	0.082	T
D53	6	0.011	0.020	0.030	0.039	0.049	0.058	0.068	0.077	C
D322	6	0.011	0.020	0.030	0.039	0.049	0.058	0.068	0.077	C

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
B51	6	0.011	0.020	0.029	0.039	0.048	0.058	0.067	0.077	T
D19	6	0.010	0.019	0.028	0.037	0.046	0.055	0.065	0.074	T
D288	6	0.010	0.019	0.028	0.037	0.046	0.055	0.065	0.074	T
D59	6	0.009	0.017	0.025	0.033	0.042	0.050	0.058	0.066	T
D328	6	0.009	0.017	0.025	0.033	0.042	0.050	0.058	0.066	T
D50	6	0.009	0.017	0.024	0.032	0.040	0.048	0.056	0.064	T
D319	6	0.009	0.017	0.024	0.032	0.040	0.048	0.056	0.064	T
D10	6	0.008	0.014	0.021	0.028	0.035	0.042	0.049	0.056	T
D279	6	0.008	0.014	0.021	0.028	0.035	0.042	0.049	0.056	T
D17	6	0.007	0.012	0.018	0.024	0.030	0.035	0.041	0.047	T
D286	6	0.007	0.012	0.018	0.024	0.030	0.035	0.041	0.047	T
D57	6	0.006	0.010	0.015	0.020	0.025	0.030	0.035	0.040	T
D326	6	0.006	0.010	0.015	0.020	0.025	0.030	0.035	0.040	T
D52	6	0.005	0.010	0.014	0.019	0.023	0.028	0.032	0.037	T
D321	6	0.005	0.010	0.014	0.019	0.023	0.028	0.032	0.037	T
D13	6	0.004	0.008	0.012	0.015	0.019	0.023	0.027	0.030	C
D282	6	0.004	0.008	0.012	0.015	0.019	0.023	0.027	0.030	C
D12	6	0.004	0.008	0.011	0.015	0.018	0.022	0.026	0.029	T
D281	6	0.004	0.008	0.011	0.015	0.018	0.022	0.026	0.029	T
B34	6	0.004	0.007	0.010	0.013	0.016	0.019	0.022	0.026	T
D15	6	0.003	0.006	0.008	0.011	0.013	0.016	0.019	0.021	T

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
D284	6	0.003	0.006	0.008	0.011	0.013	0.016	0.019	0.021	T
D55	6	0.002	0.004	0.006	0.007	0.009	0.011	0.012	0.014	T
D324	6	0.002	0.004	0.006	0.007	0.009	0.011	0.012	0.014	T
D54	6	0.002	0.003	0.005	0.006	0.008	0.009	0.011	0.012	T
D323	6	0.002	0.003	0.005	0.006	0.008	0.009	0.011	0.012	T
B35	6	0.001	0.002	0.003	0.004	0.004	0.005	0.006	0.007	C
B36	6	0.001	0.002	0.003	0.004	0.004	0.005	0.006	0.007	C
B37	6	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.007	C
B38	6	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.007	C
B39	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B40	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B41	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B42	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B43	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B44	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B45	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B46	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B47	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B48	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B49	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B53	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C

Table 4.3. Demand to capacity ratio of the Stirrups of the economical section when there is one temporary intermediate support (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.025 kN	0.050 kN	0.075 kN	0.100 kN	0.125 kN	0.150 kN	0.175 kN	0.200 kN	
B54	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B55	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B56	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B57	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B58	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B59	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B60	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B61	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B62	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B63	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B64	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B65	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
B66	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	C
D14	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	T
D283	6	0.001	0.002	0.002	0.003	0.004	0.005	0.005	0.006	T
B50	6	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.004	C
B52	6	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.004	C
B67	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

4.1.1.3. When there are two temporary intermediate supports

The critical members are stirrups if two temporary intermediate supports are provided. Therefore, the discussion in this section covers the members of the stirrups.

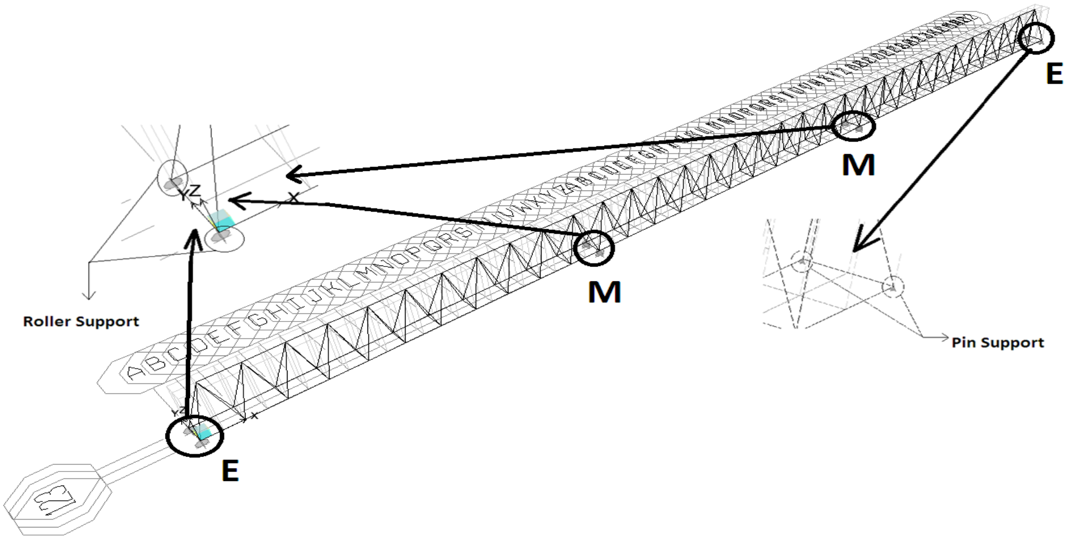

Fig.4.4. Precast joist supported at the ends by the Girder and with two temporary intermediate supports

As shown in Table 4.4 below the first members that fail are compression members around the two middle supports and as the joint load increases the members around the end support will also fail. The last column of the next table gives the type of internal axial force in the member, i.e., either compression (C) or tension (T).

The following tables show the demand to capacity ratio of the members of the above model, with two temporary intermediate supports, for different joint load. In Table 4.4 below the second column shows the position of the critical members which fail either near to the middle supports (M) or near to the End Supports (E).

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports

Label of member	Member position	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
			0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D22	M	6	0.247	0.481	0.715	0.948	1.065	1.181	1.298	1.415	C
D45	M	6	0.247	0.481	0.715	0.948	1.065	1.181	1.298	1.415	C
D291	M	6	0.247	0.481	0.715	0.948	1.065	1.181	1.298	1.415	C
D314	M	6	0.247	0.481	0.715	0.948	1.065	1.181	1.298	1.415	C
D20	M	6	0.216	0.419	0.621	0.821	0.921	1.020	1.120	1.219	C
D47	M	6	0.216	0.419	0.621	0.821	0.921	1.020	1.120	1.219	C
D289	M	6	0.216	0.419	0.621	0.821	0.921	1.020	1.120	1.219	C
D316	M	6	0.216	0.419	0.621	0.821	0.921	1.020	1.120	1.219	C
D23	M	6	0.205	0.398	0.591	0.784	0.880	0.977	1.073	1.170	C
D44	M	6	0.205	0.398	0.591	0.784	0.880	0.977	1.073	1.170	C
D292	M	6	0.205	0.398	0.591	0.784	0.880	0.977	1.073	1.170	C
D313	M	6	0.205	0.398	0.591	0.784	0.880	0.977	1.073	1.170	C
D25	M	6	0.173	0.336	0.498	0.659	0.739	0.819	0.899	0.978	C
D42	M	6	0.173	0.336	0.498	0.659	0.739	0.819	0.899	0.978	C
D294	M	6	0.173	0.336	0.498	0.659	0.739	0.819	0.899	0.978	C
D311	M	6	0.173	0.336	0.498	0.659	0.739	0.819	0.899	0.978	C
D18	M	6	0.171	0.332	0.492	0.651	0.731	0.810	0.890	0.969	C
D49	M	6	0.171	0.332	0.492	0.651	0.731	0.810	0.890	0.969	C
D287	M	6	0.171	0.332	0.492	0.651	0.731	0.810	0.889	0.969	C
D318	M	6	0.171	0.332	0.492	0.651	0.731	0.810	0.889	0.969	C
D1	E	6	0.170	0.330	0.490	0.649	0.728	0.808	0.887	0.966	C

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D66	6	0.170	0.330	0.490	0.649	0.728	0.808	0.887	0.966	C
D135	6	0.170	0.330	0.490	0.649	0.728	0.808	0.887	0.966	C
D335	6	0.170	0.330	0.490	0.649	0.728	0.808	0.887	0.966	C
D16	6	0.129	0.251	0.372	0.492	0.553	0.613	0.673	0.733	C
D51	6	0.129	0.251	0.372	0.492	0.553	0.613	0.673	0.733	C
D285	6	0.129	0.251	0.372	0.492	0.553	0.613	0.673	0.733	C
D320	6	0.129	0.251	0.372	0.492	0.553	0.613	0.673	0.733	C
D3	6	0.128	0.249	0.369	0.489	0.548	0.608	0.667	0.727	C
D64	6	0.128	0.249	0.369	0.489	0.548	0.608	0.667	0.727	C
D272	6	0.128	0.249	0.369	0.489	0.548	0.608	0.667	0.727	C
D333	6	0.128	0.249	0.369	0.489	0.548	0.608	0.667	0.727	C
D27	6	0.128	0.248	0.368	0.488	0.548	0.607	0.667	0.726	C
D40	6	0.128	0.248	0.368	0.488	0.548	0.607	0.667	0.726	C
D296	6	0.128	0.248	0.368	0.488	0.547	0.607	0.667	0.726	C
D309	6	0.128	0.248	0.368	0.488	0.547	0.607	0.667	0.726	C
D14	6	0.086	0.168	0.249	0.330	0.370	0.411	0.451	0.491	C
D53	6	0.086	0.168	0.249	0.330	0.370	0.411	0.451	0.491	C
D283	6	0.086	0.168	0.249	0.330	0.370	0.411	0.451	0.491	C
D322	6	0.086	0.168	0.249	0.330	0.370	0.411	0.451	0.491	C
D29	6	0.086	0.167	0.248	0.328	0.368	0.409	0.449	0.489	C
D38	6	0.086	0.167	0.248	0.328	0.368	0.409	0.449	0.489	C

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D298	6	0.086	0.167	0.248	0.328	0.368	0.409	0.449	0.489	C
D307	6	0.086	0.167	0.248	0.328	0.368	0.409	0.449	0.489	C
D62	6	0.086	0.166	0.246	0.327	0.366	0.406	0.446	0.486	C
D331	6	0.086	0.166	0.246	0.327	0.366	0.406	0.446	0.486	C
D5	6	0.086	0.166	0.246	0.326	0.366	0.406	0.446	0.486	C
D274	6	0.086	0.166	0.246	0.326	0.366	0.406	0.446	0.486	C
D12	6	0.044	0.085	0.126	0.167	0.188	0.208	0.229	0.249	C
D55	6	0.044	0.085	0.126	0.167	0.188	0.208	0.229	0.249	C
D281	6	0.044	0.085	0.126	0.167	0.188	0.208	0.229	0.249	C
D324	6	0.044	0.085	0.126	0.167	0.188	0.208	0.229	0.249	C
D31	6	0.043	0.084	0.124	0.165	0.185	0.205	0.226	0.246	C
D36	6	0.043	0.084	0.124	0.165	0.185	0.205	0.226	0.246	C
D300	6	0.043	0.084	0.124	0.165	0.185	0.205	0.226	0.246	C
D305	6	0.043	0.084	0.124	0.165	0.185	0.205	0.226	0.246	C
D7	6	0.043	0.083	0.124	0.164	0.184	0.204	0.224	0.244	C
D60	6	0.043	0.083	0.124	0.164	0.184	0.204	0.224	0.244	C
D276	6	0.043	0.083	0.124	0.164	0.184	0.204	0.224	0.244	C
D329	6	0.043	0.083	0.124	0.164	0.184	0.204	0.224	0.244	C
D21	6	0.041	0.080	0.119	0.158	0.178	0.197	0.217	0.236	T
D46	6	0.041	0.080	0.119	0.158	0.178	0.197	0.217	0.236	T
D290	6	0.041	0.080	0.119	0.158	0.178	0.197	0.217	0.236	T

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D315	6	0.041	0.080	0.119	0.158	0.178	0.197	0.217	0.236	T
D19	6	0.035	0.068	0.101	0.134	0.150	0.167	0.183	0.200	T
D48	6	0.035	0.068	0.101	0.134	0.150	0.167	0.183	0.200	T
D288	6	0.035	0.068	0.101	0.134	0.150	0.167	0.183	0.200	T
D317	6	0.035	0.068	0.101	0.134	0.150	0.167	0.183	0.200	T
D24	6	0.034	0.067	0.099	0.131	0.147	0.163	0.180	0.196	T
D43	6	0.034	0.067	0.099	0.131	0.147	0.163	0.180	0.196	T
D293	6	0.034	0.067	0.099	0.131	0.147	0.163	0.180	0.196	T
D312	6	0.034	0.067	0.099	0.131	0.147	0.163	0.180	0.196	T
D26	6	0.028	0.054	0.081	0.107	0.120	0.133	0.147	0.160	T
D41	6	0.028	0.054	0.081	0.107	0.120	0.133	0.147	0.160	T
D295	6	0.028	0.054	0.081	0.107	0.120	0.133	0.146	0.160	T
D310	6	0.028	0.054	0.081	0.107	0.120	0.133	0.146	0.160	T
D17	6	0.028	0.054	0.080	0.106	0.119	0.132	0.145	0.158	T
D50	6	0.028	0.054	0.080	0.106	0.119	0.132	0.145	0.158	T
D286	6	0.028	0.054	0.080	0.106	0.119	0.132	0.145	0.158	T
D319	6	0.028	0.054	0.080	0.106	0.119	0.132	0.145	0.158	T
D2	6	0.027	0.053	0.079	0.104	0.117	0.130	0.143	0.155	T
D65	6	0.027	0.053	0.079	0.104	0.117	0.130	0.143	0.155	T
D136	6	0.027	0.053	0.079	0.104	0.117	0.130	0.143	0.155	T
D334	6	0.027	0.053	0.079	0.104	0.117	0.130	0.143	0.155	T

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D4	6	0.021	0.040	0.060	0.079	0.089	0.099	0.109	0.118	T
D15	6	0.021	0.040	0.060	0.079	0.089	0.099	0.109	0.118	T
D28	6	0.021	0.040	0.060	0.079	0.089	0.099	0.109	0.118	T
D39	6	0.021	0.040	0.060	0.079	0.089	0.099	0.109	0.118	T
D52	6	0.021	0.040	0.060	0.079	0.089	0.099	0.108	0.118	T
D63	6	0.021	0.040	0.060	0.079	0.089	0.099	0.108	0.118	T
D273	6	0.021	0.040	0.060	0.079	0.089	0.099	0.108	0.118	T
D284	6	0.021	0.040	0.060	0.079	0.089	0.099	0.108	0.118	T
D297	6	0.021	0.040	0.059	0.079	0.088	0.098	0.108	0.118	T
D308	6	0.021	0.040	0.059	0.079	0.088	0.098	0.108	0.118	T
D321	6	0.021	0.040	0.059	0.079	0.088	0.098	0.108	0.118	T
D332	6	0.021	0.040	0.059	0.079	0.088	0.098	0.108	0.118	T
D13	6	0.014	0.027	0.040	0.052	0.059	0.065	0.072	0.078	T
D30	6	0.014	0.027	0.040	0.052	0.059	0.065	0.072	0.078	T
D37	6	0.014	0.027	0.040	0.052	0.059	0.065	0.072	0.078	T
D54	6	0.014	0.027	0.040	0.052	0.059	0.065	0.072	0.078	T
D282	6	0.014	0.027	0.039	0.052	0.059	0.065	0.072	0.078	T
D299	6	0.014	0.027	0.039	0.052	0.059	0.065	0.072	0.078	T
D306	6	0.014	0.027	0.039	0.052	0.059	0.065	0.072	0.078	T
D323	6	0.014	0.027	0.039	0.052	0.059	0.065	0.072	0.078	T
D6	6	0.014	0.026	0.039	0.051	0.058	0.064	0.071	0.077	T

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
D61	6	0.014	0.026	0.039	0.051	0.058	0.064	0.071	0.077	T
D275	6	0.014	0.026	0.039	0.051	0.058	0.064	0.071	0.077	T
D330	6	0.014	0.026	0.039	0.051	0.058	0.064	0.071	0.077	T
B45	6	0.011	0.022	0.033	0.044	0.049	0.054	0.060	0.065	T
B56	6	0.011	0.022	0.033	0.044	0.049	0.054	0.060	0.065	T
D11	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D32	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D35	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D56	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D280	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D301	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D304	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D325	6	0.007	0.013	0.019	0.026	0.029	0.032	0.035	0.038	T
D8	6	0.007	0.013	0.019	0.025	0.028	0.031	0.034	0.038	T
D59	6	0.007	0.013	0.019	0.025	0.028	0.031	0.034	0.038	T
D277	6	0.007	0.013	0.019	0.025	0.028	0.031	0.034	0.038	T
D328	6	0.007	0.013	0.019	0.025	0.028	0.031	0.034	0.038	T
B34	6	0.004	0.008	0.013	0.017	0.019	0.021	0.023	0.025	T
B43	6	0.002	0.003	0.005	0.007	0.007	0.008	0.009	0.010	C
B47	6	0.002	0.003	0.005	0.007	0.007	0.008	0.009	0.010	C
B54	6	0.002	0.003	0.005	0.007	0.007	0.008	0.009	0.010	C

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
B58	6	0.002	0.003	0.005	0.007	0.007	0.008	0.009	0.010	C
B35	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B36	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B37	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B38	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B39	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B40	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B41	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B42	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B48	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B49	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B50	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B51	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B52	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B53	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B59	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B60	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B61	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B62	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B63	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B64	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C

Table 4.4. Demand to capacity ratio of the Stirrups of the economical section when there are two temporary intermediate supports (Continued)

Label of member	Φ (mm)	Demand to Capacity ratio for different joint load								Axial Load
		0.050 kN	0.100 kN	0.150 kN	0.200 kN	0.225 kN	0.250 kN	0.275 kN	0.300 kN	
B65	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B66	6	0.002	0.003	0.005	0.006	0.007	0.008	0.008	0.009	C
B44	6	0.001	0.003	0.004	0.005	0.006	0.006	0.007	0.008	C
B46	6	0.001	0.003	0.004	0.005	0.006	0.006	0.007	0.008	C
B55	6	0.001	0.003	0.004	0.005	0.006	0.006	0.007	0.008	C
B57	6	0.001	0.003	0.004	0.005	0.006	0.006	0.007	0.008	C
D10	6	0.001	0.002	0.003	0.004	0.005	0.005	0.005	0.006	C
D57	6	0.001	0.002	0.003	0.004	0.005	0.005	0.005	0.006	C
D279	6	0.001	0.002	0.003	0.004	0.005	0.005	0.005	0.006	C
D326	6	0.001	0.002	0.003	0.004	0.005	0.005	0.005	0.006	C
D9	6	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003	T
D33	6	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003	C
D34	6	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003	C
D58	6	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.003	T
D278	6	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	T
D302	6	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	C
D303	6	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	C
D327	6	0.000	0.001	0.001	0.002	0.002	0.002	0.002	0.002	T
B67	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

4.1.1.4. When there are three temporary intermediate supports

The critical members are stirrups if three temporary intermediate supports are provided. Therefore, the discussion in this section covers the members of the stirrups.

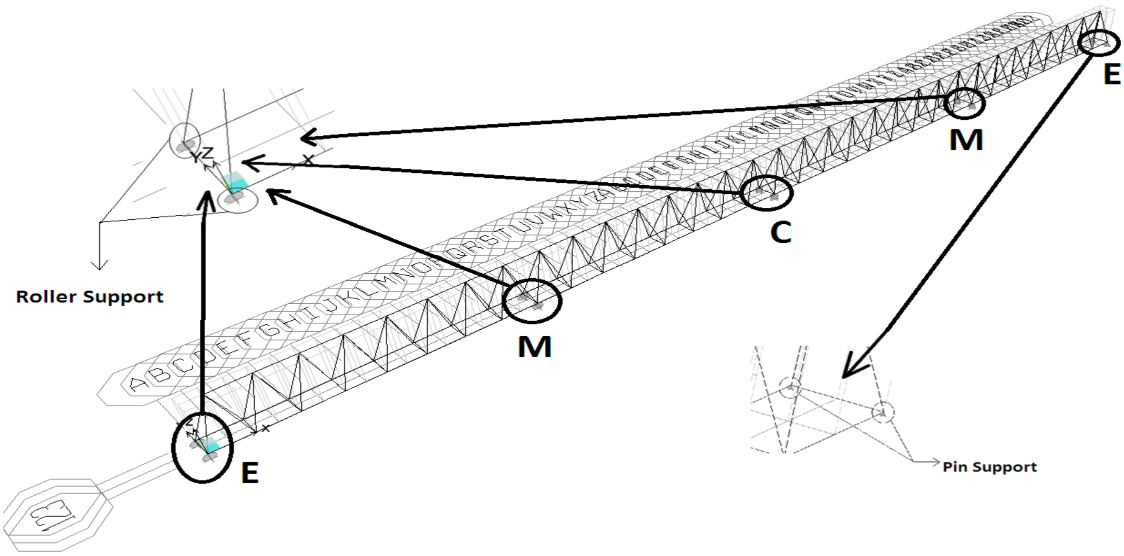

Fig.4.5. Precast joist supported at the ends by the Girder and with three temporary intermediate supports

As shown in the Table 4.5 below the first members that fail are compression members around the three middle supports and as the joint load increases the members around the end support will also fail. The last column of the next table gives the type of internal axial force in the member, i.e., either compression (C) or tension (T).

The following tables show the demand to capacity ratio of the members of the above model, with three temporary intermediate supports, for different joint load. In Table 4.5 the second column shows the position of the critical members which fail near to the end supports (E), or near to the Middle Supports (M) or near to the central support (C).

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports

label of member	Member position	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
			0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D51	M	6	0.176	0.508	0.840	0.923	1.006	1.089	1.171	1.254	1.337	C
D320	M	6	0.176	0.508	0.840	0.923	1.006	1.089	1.171	1.254	1.337	C
D16	M	6	0.172	0.497	0.822	0.903	0.984	1.065	1.146	1.227	1.308	C
D285	M	6	0.172	0.497	0.822	0.903	0.984	1.065	1.146	1.227	1.308	C
D50	M	6	0.165	0.477	0.788	0.866	0.944	1.022	1.100	1.177	1.255	C
D319	M	6	0.165	0.477	0.788	0.866	0.944	1.022	1.100	1.177	1.255	C
D33	C	6	0.163	0.471	0.779	0.856	0.933	1.010	1.087	1.163	1.240	C
D302	C	6	0.163	0.471	0.779	0.856	0.933	1.010	1.087	1.163	1.240	C
D32	C	6	0.146	0.422	0.697	0.766	0.835	0.904	0.973	1.042	1.111	C
D301	C	6	0.146	0.422	0.697	0.766	0.835	0.904	0.973	1.042	1.111	C
D53	M	6	0.142	0.409	0.674	0.739	0.805	0.871	0.936	1.001	1.067	C
D322	M	6	0.142	0.409	0.674	0.739	0.805	0.871	0.936	1.001	1.067	C
D17	M	6	0.141	0.405	0.670	0.736	0.802	0.868	0.934	1.000	1.066	C
D286	M	6	0.141	0.405	0.670	0.736	0.802	0.868	0.934	1.000	1.066	C
D14	M	6	0.138	0.396	0.653	0.717	0.780	0.844	0.907	0.971	1.034	C
D283	M	6	0.138	0.396	0.653	0.717	0.780	0.844	0.907	0.971	1.034	C
D48	M	6	0.131	0.378	0.623	0.683	0.744	0.805	0.865	0.926	0.986	C
D317	M	6	0.131	0.378	0.623	0.683	0.744	0.805	0.865	0.926	0.986	C
D35	C	6	0.129	0.370	0.610	0.670	0.729	0.789	0.848	0.907	0.967	C
D304	C	6	0.129	0.370	0.610	0.670	0.729	0.789	0.848	0.907	0.967	C
D1	E	6	0.120	0.346	0.572	0.628	0.684	0.740	0.796	0.851	0.907	C

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D135	6	0.120	0.346	0.572	0.628	0.684	0.740	0.796	0.851	0.907	C
D66	6	0.116	0.334	0.551	0.605	0.659	0.713	0.767	0.821	0.875	C
D335	6	0.116	0.334	0.551	0.605	0.659	0.713	0.767	0.821	0.875	C
D30	6	0.112	0.321	0.529	0.581	0.633	0.684	0.736	0.787	0.839	C
D299	6	0.112	0.321	0.529	0.581	0.633	0.684	0.736	0.787	0.839	C
D19	6	0.106	0.305	0.502	0.551	0.600	0.649	0.698	0.747	0.796	C
D288	6	0.106	0.305	0.502	0.551	0.600	0.649	0.698	0.747	0.796	C
D55	6	0.098	0.281	0.463	0.509	0.554	0.600	0.645	0.690	0.735	C
D324	6	0.098	0.281	0.463	0.509	0.554	0.600	0.645	0.690	0.735	C
D12	6	0.093	0.269	0.443	0.487	0.530	0.574	0.617	0.660	0.703	C
D281	6	0.093	0.269	0.443	0.487	0.530	0.574	0.617	0.660	0.703	C
D46	6	0.087	0.250	0.412	0.452	0.493	0.533	0.574	0.614	0.654	C
D315	6	0.087	0.250	0.412	0.452	0.493	0.533	0.574	0.614	0.654	C
D37	6	0.084	0.243	0.400	0.440	0.479	0.518	0.557	0.597	0.636	C
D306	6	0.084	0.243	0.400	0.440	0.479	0.518	0.557	0.597	0.636	C
D3	6	0.078	0.225	0.372	0.408	0.444	0.481	0.517	0.554	0.590	C
D272	6	0.078	0.225	0.372	0.408	0.444	0.481	0.517	0.554	0.590	C
D64	6	0.074	0.213	0.351	0.386	0.420	0.454	0.489	0.523	0.557	C
D333	6	0.074	0.213	0.351	0.386	0.420	0.454	0.489	0.523	0.557	C
D28	6	0.067	0.193	0.319	0.350	0.381	0.413	0.444	0.475	0.506	C
D297	6	0.067	0.193	0.319	0.350	0.381	0.413	0.444	0.475	0.506	C

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D21	6	0.061	0.176	0.291	0.320	0.348	0.377	0.405	0.434	0.463	C
D290	6	0.061	0.176	0.291	0.320	0.348	0.377	0.405	0.434	0.463	C
D57	6	0.055	0.160	0.264	0.290	0.315	0.341	0.367	0.393	0.419	C
D326	6	0.055	0.160	0.264	0.290	0.315	0.341	0.367	0.393	0.419	C
D10	6	0.051	0.147	0.243	0.267	0.291	0.315	0.339	0.362	0.386	C
D279	6	0.051	0.147	0.243	0.267	0.291	0.315	0.339	0.362	0.386	C
D44	6	0.045	0.128	0.212	0.233	0.254	0.274	0.295	0.316	0.337	C
D313	6	0.045	0.128	0.212	0.233	0.254	0.274	0.295	0.316	0.337	C
D39	6	0.042	0.121	0.200	0.220	0.239	0.259	0.279	0.298	0.318	C
D308	6	0.042	0.121	0.200	0.220	0.239	0.259	0.279	0.298	0.318	C
D5	6	0.036	0.102	0.169	0.185	0.202	0.218	0.235	0.251	0.268	C
D274	6	0.036	0.102	0.169	0.185	0.202	0.218	0.235	0.251	0.268	C
D62	6	0.031	0.090	0.148	0.163	0.177	0.192	0.206	0.221	0.235	C
D331	6	0.031	0.090	0.148	0.163	0.177	0.192	0.206	0.221	0.235	C
D52	6	0.029	0.085	0.140	0.153	0.167	0.181	0.195	0.209	0.222	T
D321	6	0.029	0.085	0.140	0.153	0.167	0.181	0.195	0.209	0.222	T
D15	6	0.029	0.083	0.136	0.150	0.163	0.177	0.190	0.204	0.217	T
D284	6	0.029	0.083	0.136	0.150	0.163	0.177	0.190	0.204	0.217	T
D49	6	0.028	0.079	0.131	0.144	0.157	0.170	0.183	0.196	0.209	T
D318	6	0.028	0.079	0.131	0.144	0.157	0.170	0.183	0.196	0.209	T
D34	6	0.027	0.078	0.129	0.142	0.155	0.168	0.181	0.193	0.206	T

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D303	6	0.027	0.078	0.129	0.142	0.155	0.168	0.181	0.193	0.206	T
D26	6	0.025	0.072	0.118	0.130	0.141	0.153	0.165	0.176	0.188	C
D295	6	0.025	0.072	0.118	0.130	0.141	0.153	0.165	0.176	0.188	C
D31	6	0.024	0.070	0.116	0.127	0.139	0.150	0.162	0.173	0.185	T
D300	6	0.024	0.070	0.116	0.127	0.139	0.150	0.162	0.173	0.185	T
D18	6	0.023	0.067	0.111	0.122	0.133	0.144	0.155	0.166	0.177	T
D287	6	0.023	0.067	0.111	0.122	0.133	0.144	0.155	0.166	0.177	T
D54	6	0.023	0.066	0.109	0.120	0.130	0.141	0.152	0.162	0.173	T
D323	6	0.023	0.066	0.109	0.120	0.130	0.141	0.152	0.162	0.173	T
D13	6	0.022	0.064	0.105	0.116	0.126	0.136	0.147	0.157	0.168	T
D282	6	0.022	0.064	0.105	0.116	0.126	0.136	0.147	0.157	0.168	T
D47	6	0.021	0.061	0.100	0.110	0.120	0.130	0.140	0.150	0.160	T
D316	6	0.021	0.061	0.100	0.110	0.120	0.130	0.140	0.150	0.160	T
D36	6	0.021	0.060	0.098	0.108	0.118	0.127	0.137	0.147	0.157	T
D305	6	0.021	0.060	0.098	0.108	0.118	0.127	0.137	0.147	0.157	T
D2	6	0.019	0.055	0.091	0.100	0.109	0.118	0.127	0.136	0.145	T
D136	6	0.019	0.055	0.091	0.100	0.109	0.118	0.127	0.136	0.145	T
D23	6	0.019	0.055	0.090	0.099	0.108	0.117	0.126	0.135	0.144	C
D292	6	0.019	0.055	0.090	0.099	0.108	0.117	0.126	0.135	0.144	C
D65	6	0.019	0.053	0.088	0.097	0.105	0.114	0.123	0.131	0.140	T
D334	6	0.019	0.053	0.088	0.097	0.105	0.114	0.123	0.131	0.140	T

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D29	6	0.018	0.051	0.085	0.093	0.102	0.110	0.119	0.127	0.135	T
D298	6	0.018	0.051	0.085	0.093	0.102	0.110	0.119	0.127	0.135	T
D20	6	0.017	0.049	0.080	0.088	0.096	0.104	0.112	0.120	0.128	T
D289	6	0.017	0.049	0.080	0.088	0.096	0.104	0.112	0.120	0.128	T
D56	6	0.016	0.045	0.075	0.082	0.089	0.097	0.104	0.111	0.119	T
D325	6	0.016	0.045	0.075	0.082	0.089	0.097	0.104	0.111	0.119	T
D11	6	0.015	0.043	0.071	0.078	0.085	0.092	0.099	0.106	0.113	T
D280	6	0.015	0.043	0.071	0.078	0.085	0.092	0.099	0.106	0.113	T
D45	6	0.014	0.040	0.066	0.073	0.079	0.086	0.092	0.099	0.105	T
D314	6	0.014	0.040	0.066	0.073	0.079	0.086	0.092	0.099	0.105	T
D38	6	0.014	0.039	0.064	0.071	0.077	0.083	0.090	0.096	0.102	T
D307	6	0.014	0.039	0.064	0.071	0.077	0.083	0.090	0.096	0.102	T
D59	6	0.013	0.036	0.060	0.066	0.072	0.077	0.083	0.089	0.095	T
D328	6	0.013	0.036	0.060	0.066	0.072	0.077	0.083	0.089	0.095	C
D4	6	0.013	0.036	0.059	0.065	0.071	0.077	0.083	0.089	0.095	T
D273	6	0.013	0.036	0.059	0.065	0.071	0.077	0.083	0.089	0.095	C
D63	6	0.012	0.034	0.056	0.062	0.067	0.073	0.078	0.084	0.090	T
D332	6	0.012	0.034	0.056	0.062	0.067	0.073	0.078	0.084	0.090	T
D27	6	0.011	0.031	0.051	0.056	0.061	0.066	0.071	0.076	0.081	T
D296	6	0.011	0.031	0.051	0.056	0.061	0.066	0.071	0.076	0.081	T
D22	6	0.010	0.028	0.046	0.051	0.056	0.060	0.065	0.069	0.074	T

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D291	6	0.010	0.028	0.046	0.051	0.056	0.060	0.065	0.069	0.074	T
B59	6	0.009	0.025	0.041	0.045	0.049	0.054	0.058	0.062	0.066	T
D58	6	0.009	0.025	0.041	0.045	0.049	0.054	0.058	0.062	0.066	T
D327	6	0.009	0.025	0.041	0.045	0.049	0.053	0.057	0.061	0.065	T
D8	6	0.008	0.024	0.039	0.043	0.047	0.051	0.055	0.058	0.062	C
D277	6	0.008	0.024	0.039	0.043	0.047	0.051	0.055	0.058	0.062	C
D9	6	0.008	0.023	0.038	0.042	0.045	0.049	0.053	0.057	0.061	T
D278	6	0.008	0.023	0.038	0.042	0.045	0.049	0.053	0.057	0.061	T
B42	6	0.008	0.023	0.038	0.041	0.045	0.049	0.052	0.056	0.060	T
B50	6	0.008	0.023	0.037	0.041	0.045	0.048	0.052	0.056	0.059	T
D43	6	0.007	0.020	0.033	0.036	0.039	0.043	0.046	0.049	0.053	T
D312	6	0.007	0.020	0.033	0.036	0.039	0.043	0.046	0.049	0.053	T
D40	6	0.007	0.019	0.031	0.034	0.037	0.040	0.043	0.046	0.049	T
D309	6	0.007	0.019	0.031	0.034	0.037	0.040	0.043	0.046	0.049	T
D6	6	0.005	0.015	0.026	0.028	0.031	0.033	0.036	0.039	0.041	T
D275	6	0.005	0.015	0.026	0.028	0.031	0.033	0.036	0.039	0.041	T
D61	6	0.005	0.013	0.022	0.025	0.027	0.029	0.031	0.034	0.036	T
D330	6	0.005	0.013	0.022	0.025	0.027	0.029	0.031	0.034	0.036	T
D25	6	0.004	0.011	0.018	0.020	0.021	0.023	0.025	0.027	0.028	T
D294	6	0.004	0.011	0.018	0.020	0.021	0.023	0.025	0.027	0.028	T
B34	6	0.003	0.009	0.015	0.016	0.017	0.019	0.020	0.022	0.023	T

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
D24	6	0.003	0.008	0.013	0.015	0.016	0.017	0.019	0.020	0.021	T
D293	6	0.003	0.008	0.013	0.015	0.016	0.017	0.019	0.020	0.021	T
D60	6	0.002	0.006	0.009	0.010	0.011	0.012	0.013	0.014	0.015	T
D329	6	0.002	0.006	0.009	0.010	0.011	0.012	0.013	0.014	0.015	T
B40	6	0.002	0.005	0.008	0.009	0.010	0.011	0.011	0.012	0.013	C
B44	6	0.002	0.005	0.008	0.009	0.010	0.011	0.011	0.012	0.013	C
B48	6	0.002	0.005	0.008	0.009	0.010	0.011	0.011	0.012	0.013	C
B52	6	0.002	0.005	0.008	0.009	0.010	0.010	0.011	0.012	0.013	C
B57	6	0.002	0.005	0.008	0.009	0.010	0.010	0.011	0.012	0.013	C
B61	6	0.002	0.005	0.008	0.009	0.010	0.010	0.011	0.012	0.013	C
D42	6	0.002	0.005	0.008	0.009	0.009	0.010	0.011	0.012	0.013	C
D311	6	0.002	0.005	0.008	0.009	0.009	0.010	0.011	0.012	0.013	C
B35	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.012	0.012	C
B36	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.012	0.012	C
B37	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B38	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B39	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B45	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B46	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B47	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B53	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C

Table 4.5. Demand to capacity ratio of the Stirrups of the economical section when there are three temporary intermediate supports (Continued)

label of member	Φ (mm)	Demand to Capacity ratio for different joint load									Axial Load
		0.050 kN	0.150 kN	0.250 kN	0.275 kN	0.300 kN	0.325 kN	0.350 kN	0.375 kN	0.400 kN	
B54	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B55	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B56	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B62	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B63	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B64	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B65	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B66	6	0.002	0.005	0.008	0.008	0.009	0.010	0.011	0.011	0.012	C
B41	6	0.002	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
B43	6	0.002	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
B49	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
B51	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
B58	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
B60	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	C
D7	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	T
D276	6	0.001	0.004	0.007	0.007	0.008	0.009	0.009	0.010	0.011	T
D41	6	0.001	0.001	0.002	0.003	0.003	0.003	0.003	0.004	0.004	T
D310	6	0.001	0.001	0.002	0.003	0.003	0.003	0.003	0.004	0.004	T
B67	6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

4.1.1.5. Verification using hand calculation

The ultimate limit state requirement of the initial stage is studied by the structural software ETABS Nonlinear V.9.7.4. using Euro code. However, the design result can be cross-checked by using the procedure in EBCS-3, 1995. Two hundred sixty four members exist in each model, and in this section one specific member is selected from the above model, for a joint load of 0.275 kN with three temporary intermediate support.

Label of the member: D51 or D320 with D – C ratio of 0.923

Analysis output from ETABS Nonlinear V.9.7.4.:

P = 1.22kN, L = 0.2649 m

End Moment : Along the axis Y – Y: $-3.436*10^{-6}$kNm and $-3.558*10^{-5}$kNm

Along the axis Z – Z: $-1.254*10^{-5}$kNm and $+3.201*10^{-5}$kNm

According EBCS-3, 1995, sec. 4.5.5.2, the buckling resistance of compression members is:

$$\frac{N_{sd}}{\chi_{min} * (Af_y/\gamma_{m1})} + \frac{K_y M_{y,sd}}{W_{pl,y} * (f_y/\gamma_{m1})} + \frac{K_z M_{z,sd}}{W_{pl,z} * (f_y/\gamma_{m1})} \leq 1$$

$$\lambda_1 = 93.9\left(\frac{235}{f_y}\right)^{0.5} = 93.9\left(\frac{235}{400}\right)^{0.5} = 77.18$$

$$i = \frac{r}{2} = \frac{3}{2} = 1.5\,mm \quad and \quad l = 0.2649m$$

According to EBCS-3, 1995, for members resisting loads other than wind load,

$\lambda \leq 180.$

$$\lambda_y = \lambda_z = \frac{l}{i} = \frac{264.9mm}{1.5mm} = 176.6\,, \quad \beta_A = 1\; for\; class\; 1$$

$$\bar{\lambda}_z = \bar{\lambda}_y = \frac{\lambda_y}{\lambda_1}\sqrt{\beta_A} = \frac{176.6}{77.18}\sqrt{1} = 2.29$$

α = 0.49 from table 4.11 and table 4.10 EBCS 3, 1995

For buckling curve c, $\bar{\lambda} = 2.29$ and using interpolation

$$\chi_y = \chi_z = 0.155 \quad from\ table\ 4.9\ EBCS\ 3\ 1995$$

⇨ $\chi_{min} = 0.155$

$$\Psi_y = \frac{-3.406 * 10^{-6}}{-3.558 * 10^{-5}} = 0.096$$

$$\beta_{M,y} = 1.8 - 0.7\psi = 1.8 - (0.7 * 0.096) = 1.732$$

$$\Psi_Z = \frac{-1.254 * 10^{-5}}{3.201 * 10^{-5}} = -0.392$$

$$\beta_{M,Z} = 1.8 - 0.7\psi = 1.8 - (0.7 * -0.392) = 2.074$$

$$W_{pl,y} = W_{pl,z} = Z = \frac{d^3}{6} = \frac{6^3}{6} = 36\ mm^3$$

$$W_{el,y} = W_{el,z} = S = \frac{\pi d^3}{32} = \frac{\pi(6)^3}{32} = 21.2\ mm^3$$

$$\mu_y = \bar{\lambda}_y * \left[2 * \beta_{M,y} - 4\right] + \left[\frac{W_{pl,y} - W_{el,y}}{W_{el,y}}\right] \leq 0.9$$

$$\mu_y = 2.29 * [2 * 2.074 - 4] + \left[\frac{36 - 21.2}{21.2}\right] = -0.53 < 0.9 \quad => \mu_y = -0.53$$

$$\mu_z = \bar{\lambda}_z * \left[2 * \beta_{M,z} - 4\right] + \left[\frac{W_{pl,z} - W_{el,z}}{W_{el,z}}\right] \leq 0.9$$

$$\mu_z = 2.29 * [2 * 1.971 - 4] + \left[\frac{36 - 21.2}{21.2}\right] = 1.04 < 0.9 \quad => \mu \quad = 0.9$$

$$K_y = 1 - \frac{\mu_y * N_{sd}}{\chi_y * A * f_y} \leq 1.5$$

$$K_y = 1 - \frac{-0.53 * 1.22 * 10^3}{0.155 * 28.27 * 10^{-6} * 347.826 * 10^6} = 1.421$$

$$K_z = 1 - \frac{\mu_z * N_{sd}}{\chi_z * A * f_y} \leq 1.5$$

$$K_z = 1 - \frac{0.9 * 1.22 * 10^3}{0.155 * 28.27 * 10^{-6} * 347.826 * 10^6} = 0.280$$

Demand to capacity ratio:

$$\frac{N_{sd}}{\chi_{min} * (Af_y/\gamma_{m1})} + \frac{K_y M_{y,sd}}{W_{pl,y} * (f_y/\gamma_{m1})} + \frac{K_z M_{z,sd}}{W_{pl,z} * (f_y/\gamma_{m1})} \leq 1$$

$$\frac{1.22 * 10^3}{0.155 * \left(28.27 * 10^{-6} * (347.826 * 10^6/1.1)\right)} + \frac{1.421 * 3.56 * 10^{-2}}{3.6 * 10^{-8} * (347.826 * 10^6/1.1)} + \frac{0.280 * 3.20 * 10^{-2}}{3.6 * 10^{-8} * (347.826 * 10^6/1.1)} \leq 1$$

0.8800+0.0044+0.0008 = 0.885

But the result from ETABS Nonlinear V.9.7.4. is:

0.9190+0.0030+0.0010 = 0.923

$$RATIO = \frac{0.923}{0.885} = 1.043$$

The variation between the hand calculation and the software analysis output is less than 5%.

4.1.2. Serviceability limit state

The size of reinforcement and the corresponding deflection for different number of temporary intermediate support is shown in the table below:

Table 4.6. Maximum deflection in the precast joist

Longitudinal reinforcement		Stirrup	Maximum deflection (mm.)			
Top	Bottom		n = 0	n = 1	n = 2	n = 3
1Φ8	2Φ12	Φ6 c/c 150	56.70	2.80	0.80	0.40

By comparing the values of the above table as previously done in section 3.1.2. with Table 3.2, the number of temporary intermediate support can be decided.

Therefore, the serviceability limit state requirement for deflection is satisfied if the precast joist is supported at least by one temporary intermediate supports.

4.1.3. Temporary intermediate support

The governing limit state condition to determine the number of temporary intermediate supports in the initial stage is the ultimate limit state, because the minimum number of temporary intermediate supports required for satisfying the ultimate limit state requirement is three and one for the serviceability limit state requirement. Therefore, three temporary intermediate supports should be provided in the initial stage of construction.

4.2. FINAL STAGE

4.2.1. Ultimate limit state

Manual calculation is used to determine the flexural and shear capacity of the cross-section according to EBCS-2, 1995.

4.2.1.1. Flexural failure check

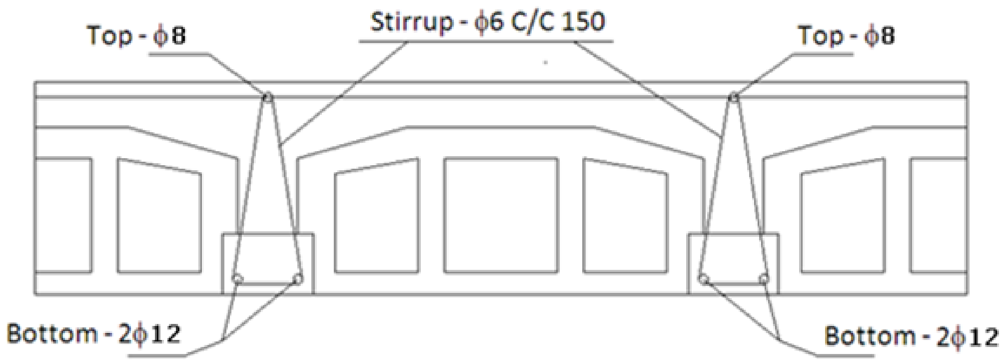

Fig.4.6. Final stage of the rib section

To use the portion of the topping above the ribbed block as the part of the rib, check either the neutral axis is above the neutral axis or not, in order to identify the section acts with T-geometry or as rectangular.

$$b_e \leq \begin{cases} {}^{L_e}/_5 + b_w \\ c/c \;\; beam\ spacing \end{cases}$$

$$b_e \leq \begin{cases} 5000\ mm/_5 + 80\ mm \\ 600\ mm \end{cases}$$

$$b_e \leq \begin{cases} 1080\ mm \\ 600\ mm \end{cases}$$

$$b_e = 600\ mm$$

$$h_f = 60\ mm$$

$$A_{s1} = 2 * \left[\frac{\pi * 12^2}{4}\right] mm^2 = 72\pi \, mm^2 = 226.19 \, mm^2$$

$$A_{s2} = \left[\frac{\pi * 8^2}{4}\right] mm^2 = 16\pi \, mm^2 = 50.26 \, mm^2$$

<u>Assume rectangular section and calculate the neutral depth</u>:

Distance from the extreme Tension fiber of reinforced concrete to the center of tension reinforcement

d' = 15+6+(12/2) = 27mm

Distance from the extreme Compression fiber of reinforced concrete to the center of Compression reinforcement

d_2 = 15+6+(8/2) =25 mm

$$^{d_2}/_{d} = ^{25 \, mm}/_{253 \, mm} = 0.099$$

<u>Trial 1</u> (Assume: $f_{s1} = f_{s2} = f_{yd} = 347.83 \, Mpa$)

$$\alpha_c = \frac{[(A_{s1} * f_{s1}) - (A_{s1} * f_{s2})]}{f_{cd} * b * d} = \frac{[(226.19 * 347.83) - (50.26 * 347.83)]}{(11.33 * 600 * 253)}$$
$$= 0.0356$$

From the General design chart:

$\varepsilon_{cm} = 0.964 \, ^0/_{00}$

$\varepsilon_{s1} = 10.0 \, ^0/_{00}$

$\varepsilon_{s2} = -\, 0.119 \, ^0/_{00}$

Therefore, $f_{s1} = f_{yd} = 347.83 \, Mpa$

$$f_{s2} = \varepsilon_{s2}E = -0.119 * 200 = -23.8\ Mpa$$

➔ f_{s2} is assumed to be 347.83 Mpa

Trial 2 (Assume: $f_{s1} = f_{yd} = 347.83\ Mpa$ $f_{s2} = -23.8\ Mpa$)

$$\alpha_c = \frac{[(A_{s1} * f_{s1}) - (A_{s1} * f_{s2})]}{f_{cd} * b * d} = \frac{[(226.19 * 347.83) - (50.26 * -23.8)]}{(11.33 * 600 * 253)}$$
$$= 0.0464$$

From the General design chart:

$\varepsilon_{cm} = 1.128\ ^0/_{00}$

$\varepsilon_{s1} = 10.0\ ^0/_{00}$

$\varepsilon_{s2} = 0.0285\ ^0/_{00}$

Therefore, $f_{s1} = f_{yd} = 347.83\ Mpa$

$$f_{s2} = \varepsilon_{s2}E = 0.028 * 200 = 5.70\ Mpa$$

➔ f_{s2} is assumed to be -23.80 Mpa

Trial 3 (Assume: $f_{s1} = f_{yd} = 347.83\ Mpa$ $f_{s2} = 5.70\ Mpa$)

$$\alpha_c = \frac{[(A_{s1} * f_{s1}) - (A_{s1} * f_{s2})]}{f_{cd} * b * d} = \frac{[(226.19 * 347.83) - (50.26 * 5.70)]}{(11.33 * 600 * 253)} = 0.0456$$

From the General design chart:

$\varepsilon_{cm} = 1.115\ ^0/_{00}$

$\varepsilon_{s1} = 10.0\ ^0/_{00}$

$\varepsilon_{s2} = 0.017\ ^0/_{00}$

Therefore, $f_{s1} = f_{yd} = 347.83\ Mpa$

$$f_{s2} = \varepsilon_{s2}E = 0.017 * 200 = 3.40\ Mpa$$

➔ f_{s2} is assumed to be 5.70 Mpa

<u>Trial 4</u> (Assume: $f_{s1} = f_{yd} = 347.83\ Mpa$ $f_{s2} = 3.40\ Mpa$)

$$\alpha_c = \frac{[(A_{s1} * f_{s1}) - (A_{s1} * f_{s2})]}{f_{cd} * b * d} = \frac{[(226.19 * 347.83) - (50.26 * 3.40)]}{(11.33 * 600 * 253)} = 0.0457$$

From the General design chart:

$\varepsilon_{cm} = 1.116\ ^0/_{00}$

$\varepsilon_{s1} = 10.0\ ^0/_{00}$

$\varepsilon_{s2} = 0.018\ ^0/_{00}$

Therefore, $f_{s1} = f_{yd} = 347.83\ Mpa$

$$f_{s2} = \varepsilon_{s2}E = 0.018 * 200 = 3.60\ Mpa$$

➔ f_{s2} is assumed to be 3.40 Mpa

<u>Trial 5</u> (Assume: $f_{s1} = f_{yd} = 347.83\ Mpa$ $f_{s2} = 3.60\ Mpa$)

$$\alpha_c = \frac{[(A_{s1} * f_{s1}) - (A_{s1} * f_{s2})]}{f_{cd} * b * d} = \frac{[(226.19 * 347.83) - (50.26 * 3.40)]}{(11.33 * 600 * 253)} = 0.0457$$

From the General design chart:

$\varepsilon_{cm} = 1.116\ ^0/_{00}$

$\varepsilon_{s1} = 10.0\ {}^{0}/_{00}$

$\varepsilon_{s2} = 0.018\ {}^{0}/_{00}$

Therefore, $f_{s1} = f_{yd} = 347.83\ Mpa$

$$f_{s2} = \varepsilon_{s2}E = 0.018 * 200 = 3.60\ Mpa$$

Hence, the assumption is correct.

$k_x = 0.1003$ => X = 0.1004*253mm = 25.40 mm < h_f; h_f = 60 mm

$$M_{sd} = M_{sd,1} + M_{sd,2}$$

$$M_{sd} = T_{s1}Z + C_s(d - d_2')$$

$$M_{sd,1} = T_{s1}Z$$

$$T_{s1} = T_s - T_{s2}$$

$$T_s = A_{s1} * f_{s1} = A_{s1} * f_{yd}$$

$$T_{s2} = A_{s2} * f_{s2}$$

$$T_{s1} = A_{s1} * f_{yd} - A_{s2} * f_{s2}$$

$$M_{sd,1} = \left(A_{s1} * f_{yd} - A_{s2} * f_{s2}\right) * Z$$

From the design chart:

$$\beta_c = 0.035$$

⇨ $Z = d * [1 - \beta_c] = 253(1 - 0.035) = 244.145\ mm$

$$M_{sd,1} = ([226.19\ mm^2 * 347.83\ N/mm^2] - [50.26\ mm^2 * 3.6\ N/mm^2]) * 244.145mm$$

⇨ $M_{sd,1} = 19.16 * 10^6 Nmm = 19.16\ kNm$

$$M_{sd,2} = C_s(d - d_2')$$

$$M_{sd,2} = [(50.26\, mm^2) * (3.6\ \ N/mm^2)] * [253\, mm - 25mm]$$

$$M_{sd,1} = 41.25 *\ 10^3 Nmm = 0.04125\, kNm$$

$$M_{sd} = M_{sd,1} +\ M_{sd,2}$$

$$M_{sd} = 19.16\, kNm +\ 0.04125\, kNm = 19.20\, kNm$$

$$\omega_1 = \frac{8 * M_{max}}{l^2} = \frac{8 * 19.20}{5^2} = 6.144\, kN/m$$

4.2.1.2. Shear failure check

For ϕ6 c/c 150, the shear failure check is done according to EBCS – 2 1995, Sec. 4.5.3.

For ϕ6 c/c 150,

$$V_s = \frac{A_v * d * f_{yd}}{S}$$

$$A_v = 2 * a_s = 2 * \left(\frac{\pi * 6^2}{4}\right) = 56.55\, mm^2$$

$$d = 280mm - \left(15 + 6 + \left(\frac{14}{2}\right)\right) mm = 252mm$$

$$f_{yd} = 260\, {}^{N}\!/_{mm^2}\, \& \quad S = 150\, mm$$

$$V_s = \frac{2 * a_s * f_{yd} * d}{S}$$

$$V_s = \frac{56.55\, mm^2 * 260.870\, {}^{N}\!/_{mm^2} * 252\, mm}{150\, mm} = 24.837\, kN$$

$V_C = 0.25 * f_{ctd} * K_1 * K_2 * b_w * d$

$f_{ctd} = 1.031\ Mpa = 1.031\ {}^{N}/_{mm^2}$

In addition to the top reinforcement in the precast joist, assume 2Φ14 reinforcement is provided at the supports, in addition to the reinforcement for in the precast section.

Therefore, take: $A_S = 2 * \pi * 7^2 + \pi * 4^2 = 358.14\ mm^2$

$$\rho = \frac{A_S}{b_w * d} = \frac{358.14\ mm^2}{120mm * 252mm} = 11.94 * 10^{-3}$$

$K_1 = 1 + 50\rho = 1 + 50 * (11.94 * 10^{-3}) = 1.597 < 2.0$

$K_2 = 1.6 - d = 1.6 - 0.25 = 1.35 \geq 1.0$

$$V_C = 0.25 * 1.031\ {}^{N}/_{mm^2} * 1.597 * 1.35 * 80mm * 252mm = 11{,}20.00\ N$$

$$= 11.20kN$$

$V_T = V_C + V_S = 11.20\ kN + 24.84\ kN = 36.04\ kN$

According to EBCS-2, 1995 the limiting value to avoid the diagonal compression failure is:

$$V_{Rd} = 0.25 * f_{cd} * b_w * d = 0.25 * 11.33\ {}^{N}/_{mm^2} * 600mm * 253\ mm$$

$$= 429{,}973.5\ N$$

$=> \qquad V_{Rd} = 429.97\ kN$

Therefore, the section is safe against diagonal compression failure.

$$V_{max} = \frac{w * l}{2}$$

$$=> \qquad w = \frac{2 * V_{max}}{l} = \frac{2 * V_{max}}{5} = 0.4 * V_{max} = 0.4 * 36.04 \frac{kN}{m} = 14.42\ kN/m$$

$P = \min\ (\omega_1, \omega_2) = \omega_1 = 6.144\ kN/m$

This implies that the maximum load the final section can carry in the final stage is 6.144kN/m, and it is greater than the load acting on the section. The load acting on the section is 5.907 kN/m. Therefore, it satisfies the ultimate limit state requirement of the final stage.

4.2.2. Serviceability limit state

According to EBCS-2, 1995 the deflection requirement of any part of a structure may be ensured by compliance with the requirement for a minimum effective depth. And in section 3.2.2 the requirement of minimum effective depth for the final stage is determined to be 208.33 mm. And the total depth of the section is 280mm.

$D_{required}$ = 208.33 mm +(15mm + 6mm + (14/2)mm)= $\underline{236.33\ mm}$ < $D_{provided}$ = 280 mm

Therefore, the final stage deflection requirement is satisfied.

5. RESULT AND DISCUSSION

The failure modes of a precast joist vary depending on the arrangement and size of reinforcement as well as the number of temporary intermediate support in the initial stage. The reinforcement bars in a model can be categorized into three depending on their position; top reinforcement, bottom reinforcement and stirrups. The discussion in the following section covers the results of ultimate limit state and serviceability limit state for both the initial and final stage of construction.

5.1. INITIAL STAGE

The demand to capacity ratio is the ratio of the internal force due to the external load and the load carrying capacity of the section. Therefore, the demand to capacity ratio of a member in a precast joist is not significantly affected by the size of the other members because of the limited size of members used for this study. If there is large difference in the size of the members, the internal force of the members due to external load could be affected by the stiffness of the members. Practically from the design output, i.e., from 0, it can be observed that, the variation of the member size of any one of the above mentioned categories do not have a significant effect on the other.

5.1.1. Ultimate limit state

The ultimate limit state condition in the initial stage is influenced by the number of temporary intermediate supports. The Study on the one hundred twenty eight models has been done with a concentrated joint load of 0.275 kN on the precast joist. The design joint load in the initial stage is 0.266 kN as shown in Table 2.1. Therefore, the following section will present the summary table for both cases.

Table 5.1. Summary table for demand to capacity ratio of the critical members

Position	Joint load (kN)	Size of reinforcement	Number of temporary intermediate supports			
			0	1	2	3
Top reinforcement	0.275	1Ø8	5.29	0.86	0.39	0.21
		1Ø10	2.78	0.46	0.21	0.12
		1Ø12	1.73	0.32	0.13	0.07
		1Ø14	1.20	0.24	0.10	0.06
	0.266	1ϕ8	5.10	0.83	0.38	0.21
		1ϕ10	2.65	0.44	0.20	0.11
		1ϕ12	1.68	0.30	0.13	0.07
		1ϕ14	1.14	0.23	0.09	0.05
Bottom reinforcement	0.275	2Ø8	1.50	0.60	0.21	0.12
		2Ø10	0.96	0.36	0.14	0.08
		2Ø12	0.66	0.27	0.11	0.07
		2Ø14	0.52	0.24	0.11	0.07
	0.266	2ϕ8	1.45	0.57	0.20	0.11
		2ϕ10	0.94	0.35	0.13	0.08
		2ϕ12	0.66	0.26	0.11	0.07
		2ϕ14	0.50	0.23	0.10	0.07
Stirrup	0.275	Ø6 c/c 150	3.65	2.10	1.30	0.95
		Ø8 c/c 150	1.23	0.76	0.45	0.33
	0.266	ϕ6 c/c 150	3.51	2.05	1.25	0.89
		ϕ8 c/c 150	1.19	0.73	0.44	0.32

5.1.1.1. Top reinforcement

To satisfy the ultimate limit state requirement one temporary intermediate support is enough for all the above cases.

5.1.1.2. Bottom reinforcement

The number of temporary intermediate support to satisfy the ultimate limit state requirement is one, if 2ϕ8 bottom reinforcement is provided. But for the other cases no temporary intermediate support is required.

5.1.1.3. Stirrups

For the precast joist discussed above the minimum number of supports required for all models in order to have safe system in the initial stage can be categorized into two. If the stirrup is ϕ6c/c150 three temporary intermediate supports are required, but for Stirrup of ϕ8c/c150 one temporary intermediate support should be provided.

5.1.2. Serviceability limit state

The deflection requirement is satisfied if and only if temporary intermediate support is provided for the precast section as summarized below. The table below summarizes the minimum number of supports required for all models in order to have deflection in the initial stage within the limiting boundary. The grouping is according to section 3.1.

Table 5.2. The minimum number of temporary intermediate supports required for all models

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
n	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

n - number of temporary intermediate support

The serviceability limit state requirement of a system is checked if it satisfies the ultimate limit state requirement because it is a system with one or more collapsed members. The table below summarizes the deflection of the precast system in Table 3.3 only for the systems that satisfies the ultimate limit state requirement.

Table 5.3. The deflection of the precast system in the initial stage that satisfy the ultimate limit state requirement

Model	Longitudinal reinforcement		Stirrup	Maximum deflection (mm.)			
	Top	Bottom		n = 0	n = 1	n = 2	n = 3
1	1Φ8	2Φ8	Φ6 c/c 150	F	F	F	0.40
2	1Φ8	2Φ8	Φ8 c/c 150	F	2.70	0.70	0.20
3	1Φ8	2Φ10	Φ6 c/c 150	F	F	F	0.40
4	1Φ8	2Φ10	Φ8 c/c 150	F	2.50	0.60	0.40
5	1Φ8	2Φ12	Φ6 c/c 150	F	F	F	0.40
6	1Φ8	2Φ12	Φ8 c/c 150	F	2.30	0.60	0.20
7	1Φ8	2Φ14	Φ6 c/c 150	F	F	F	0.30
8	1Φ8	2Φ14	Φ8 c/c 150	F	2.20	0.60	0.20
9	1Φ10	2Φ8	Φ6 c/c 150	F	F	F	0.30
10	1Φ10	2Φ8	Φ8 c/c 150	F	2.20	0.60	0.20
11	1Φ10	2Φ10	Φ6 c/c 150	F	F	F	0.30
12	1Φ10	2Φ10	Φ8 c/c 150	F	2.00	0.50	0.30
13	1Φ10	2Φ12	Φ6 c/c 150	F	F	F	0.70
14	1Φ10	2Φ12	Φ8 c/c 150	F	1.80	0.50	0.20
15	1Φ10	2Φ14	Φ6 c/c 150	F	F	F	0.30
16	1Φ10	2Φ14	Φ8 c/c 150	F	1.70	0.50	0.20

Table 5.3. The deflection of the precast system in the initial stage that satisfy the ultimate limit state requirement (Continued)

Model	Longitudinal reinforcement		Stirrup	Maximum deflection (mm.)			
	Top	Bottom		n = 0	n = 1	n = 2	n = 3
17	1Φ12	2Φ8	Φ6 c/c 150	F	F	F	0.30
18	1Φ12	2Φ8	Φ8 c/c 150	F	1.90	0.50	0.20
19	1Φ12	2Φ10	Φ6 c/c 150	F	F	F	0.30
20	1Φ12	2Φ10	Φ8 c/c 150	F	1.70	0.50	0.30
21	1Φ12	2Φ12	Φ6 c/c 150	F	F	F	0.30
22	1Φ12	2Φ12	Φ8 c/c 150	F	1.60	0.40	0.20
23	1Φ12	2Φ14	Φ6 c/c 150	F	F	F	0.30
24	1Φ12	2Φ14	Φ8 c/c 150	F	1.50	0.40	0.20
25	1Φ14	2Φ8	Φ6 c/c 150	F	F	F	0.30
26	1Φ14	2Φ8	Φ8 c/c 150	F	1.80	0.50	0.20
27	1Φ14	2Φ10	Φ6 c/c 150	F	F	F	0.30
28	1Φ14	2Φ10	Φ8 c/c 150	F	1.50	0.40	0.30
29	1Φ14	2Φ12	Φ6 c/c 150	F	F	F	0.30
30	1Φ14	2Φ12	Φ8 c/c 150	F	1.40	0.40	0.20
31	1Φ14	2Φ14	Φ6 c/c 150	F	F	F	0.30
32	1Φ14	2Φ14	Φ8 c/c 150	F	1.30	0.40	0.20

n – The number of temporary intermediate supports.
F – The precast system that does not satisfy the ultimate limit state requirement.

Since the governing limit state is the ultimate limit state, all the models that satisfies Ultimate limit state requirement has deflection with in the limiting range for the initial stage.

5.1.3. Failure mode in the initial stage

The Capacity of the members of a precast system can be studied independently by referring Table 3.1 in section 3.1 and Table 5.1 in section 5.1. Hence, the cases in which different failure modes occur in the initial stage can be summarized as follows:

<u>Failure mode 1 (Buckling of stirrups)</u>

For stirrup with ϕ6 c/c 150

- Models in group 1, 2, 3 and 4 with one, two or three temporary intermediate support
- Models in group 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16 without, with one, two or three temporary intermediate supports

For stirrup with ϕ8 c/c 150

- Models in group 1, 2, 3 and 4 with two or three temporary intermediate support
- Models in group 5, 6, 7, 8, 9, 10, 11, 12 and 13 with one, two or three temporary intermediate supports
- Models in group 14, 15 and 16 without, with one, two or three temporary intermediate supports

<u>Failure mode 2 (Buckling of top reinforcement)</u>

For stirrup with ϕ6 c/c 150

- Models in group 1, 2, 3, 4 without temporary intermediate support

For stirrup with ϕ8 c/c 150

- Models in group 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 without temporary intermediate support
- Models in group 1, 2, 3 and 4 with one temporary intermediate support

Failure mode 3 (Yielding of bottom reinforcement)

Models in group 13 without temporary intermediate support, ϕ8 c/c 150

In the above explanation for failure mode of the different models, it can be clearly seen that the mode of failure shifts towards buckling of stirrups as the number of intermediate support is increased. For instance, if temporary intermediate support is provided, models in group 5, 6, 7, 8, 9, 10, 11, 12 and 13 with ϕ8 c/c 150 has a failure mode of buckling of top reinforcement except the last which has a failure mode of yielding of bottom reinforcement. But with one temporary intermediate support, the failure mode shifts to "buckling of stirrup".

Therefore, when temporary intermediate support is provided for the precast joist element, the failure by "buckling of stirrups" should be observed properly by the responsible site engineer.

5.2. FINAL STAGE

5.2.1. Ultimate limit state

5.2.1.1. Flexure design

Table 5.4. Flexural capacity of the precast joist for different size of longitudinal reinforcement

Group	1	2	3	4	5	6	7	8
Top reinforcement	1Φ8	1Φ8	1Φ8	1Φ8	1Φ10	1Φ10	1Φ10	1Φ10
Bottom reinforcement	1Φ8	1Φ10	1Φ12	1Φ14	1Φ8	1Φ10	1Φ12	1Φ14
M (kNm)	8.77	13.50	19.20	25.81	8.81	13.52	19.22	25.81
Group	9	10	11	12	13	14	15	16
Top reinforcement	1Φ12	1Φ12	1Φ12	1Φ12	1Φ14	1Φ14	1Φ14	1Φ14
Bottom reinforcement	1Φ8	1Φ10	1Φ12	1Φ14	1Φ8	1Φ10	1Φ12	1Φ14
M (kNm)	8.86	13.55	19.22	25.81	8.93	13.60	19.24	25.81

From the calculation in section 3.2.1.1 the maximum span moment in the section is 18.460 kNm. Therefore, the size of the bottom reinforcement should be at least 2ϕ12 to satisfy the requirement of the ultimate limit state.

5.2.1.2. Shear design

Table 5.5. Shear capacity of the precast joist for different size of stirrups

Reinforcement	Ø6 c/c 150	Ø8 c/c 150
Maximum distributed load (kN/m)	14.42	21.96

From the calculation in section 2.4.2 the maximum line load acting on the section in the final stage is 5.907 kN/m, and as discussed in Appendix B, both Ø6 c/c 150 and Ø8 c/c 150 can satisfy the requirement of the ultimate limit state.

5.2.2. Serviceability limit state

In the final stage the minimum effective depth required is 228.33 mm, the actual effective depth of the section is between 250 mm and 255 mm.

The range can be calculated as follows,

$$d_{min} = 280mm - [15mm + 8mm + (14mm/2)] = 250mm,$$

$$d_{max} = 280mm - [15mm + 6mm + (8mm/2)] = 255mm$$

Therefore, the deflection requirement is satisfied in the final stage for all models.

5.3. GUIDELINE FOR PRECAST JOIST DESIGN

In this study, thirty two types of precast joist are modeled, analyzed and designed. The table below summarizes the number of temporary intermediate supports required in the initial stage and which of the precast joists fail in the final stage of construction.

Table 5.6. Guideline for Precast Joist Design

Model	Longitudinal reinforcement		Stirrup	Initial stage		Final stage	
	Top	Bottom		Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state
1	*1Φ8*	*2Φ8*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
2	*1Φ8*	*2Φ8*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
3	*1Φ8*	*2Φ10*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
4	*1Φ8*	*2Φ10*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
5	**1Φ8**	**2Φ12**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
6	**1Φ8**	**2Φ12**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
7	**1Φ8**	**2Φ14**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
8	**1Φ8**	**2Φ14**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
9	*1Φ10*	*2Φ8*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
10	*1Φ10*	*2Φ8*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
11	*1Φ10*	*2Φ10*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
12	*1Φ10*	*2Φ10*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
13	**1Φ10**	**2Φ12**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
14	**1Φ10**	**2Φ12**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
15	**1Φ10**	**2Φ14**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**

Table 5.6. Guideline for Precast Joist Design (Continued)

Model	Longitudinal reinforcement		Stirrup	Initial stage		Final stage	
	Top	Bottom		Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state
16	**1Φ10**	**2Φ14**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
17	*1Φ12*	*2Φ8*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
18	*1Φ12*	*2Φ8*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
19	*1Φ12*	*2Φ10*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
20	*1Φ12*	*2Φ10*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
21	**1Φ12**	**2Φ12**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
22	**1Φ12**	**2Φ12**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
23	**1Φ12**	**2Φ14**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
24	**1Φ12**	**2Φ14**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
25	*1Φ14*	*2Φ8*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
26	*1Φ14*	*2Φ8*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
27	*1Φ14*	*2Φ10*	*Φ6 c/c 150*	*n = 3*	*n = 1*	*F*	*P*
28	*1Φ14*	*2Φ10*	*Φ8 c/c 150*	*n = 1*	*n = 1*	*F*	*P*
29	**1Φ14**	**2Φ12**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
30	**1Φ14**	**2Φ12**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**
31	**1Φ14**	**2Φ14**	**Φ6 c/c 150**	**n = 3**	**n = 1**	**P**	**P**
32	**1Φ14**	**2Φ14**	**Φ8 c/c 150**	**n = 1**	**n = 1**	**P**	**P**

n - It is the number of temporary intermediate supports required to satisfy the limit state requirement

F - The precast joist does not satisfy the limit state requirement

P - The precast joist satisfies the limit state requirement

6. CONCLUSION AND RECOMMENDATION

i. Temporary intermediate supports are required to satisfy the requirement of limit state in the initial stage. The number of temporary intermediate supports required in the initial stage to satisfy the ultimate limit state and the deflection requirement of the serviceability limit state can be categorized into two:
   - For stirrup ϕ6c/c150 three temporary intermediate supports should be provided, because the governing condition is the ultimate limit state requirement
   - For stirrup ϕ8c/c150 one temporary intermediate support is enough to satisfy both the ultimate limit state and the serviceability limit state requirement.

ii. The failure mode in the initial stage shifts to buckling of stirrups as the number of intermediate support increases.

iii. In the concrete pouring stage all the members are covered and it is not possible to observe the premature failure. For inspection purpose, before setting of concrete, the supervisor can remove the concrete and check the failure mode.

iv. All of the models in each group can satisfy the requirement of the initial stage if appropriate number of temporary intermediate support is provided. However, all of them do not satisfy the ultimate limit state requirement of the final stage. Therefore, only the models that are safe in the final stage can be used for practical purpose.

v. A guideline has been proposed for a specific geometry. And in the current practice of the construction industry, the Engineers tend to vary the geometry and the reinforcement. And if we need additional guideline for other cases, the study should be done to access premature failure mode.

vi. This study covers the precast joist element for the same geometry and for a floor construction of residential building, and this can be extended for other categories of building that has different geometry. In the same way the study should be done to prepare additional guideline and to access premature failure mode.

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Appendix A. Calculation of Cross Sectional Area

Here cross sectional area of the components of the precast slab system is calculated to determine the design load for the final stage and for the three sub-section of the initial stage.

A.1. Precast Block

After placing of the precast joist on the girder, the precast block will be laid on the precast joist. The precast block is a filling block that has no structural use in the precast joist slab system and it stay into position by the cementing effect of the concrete.

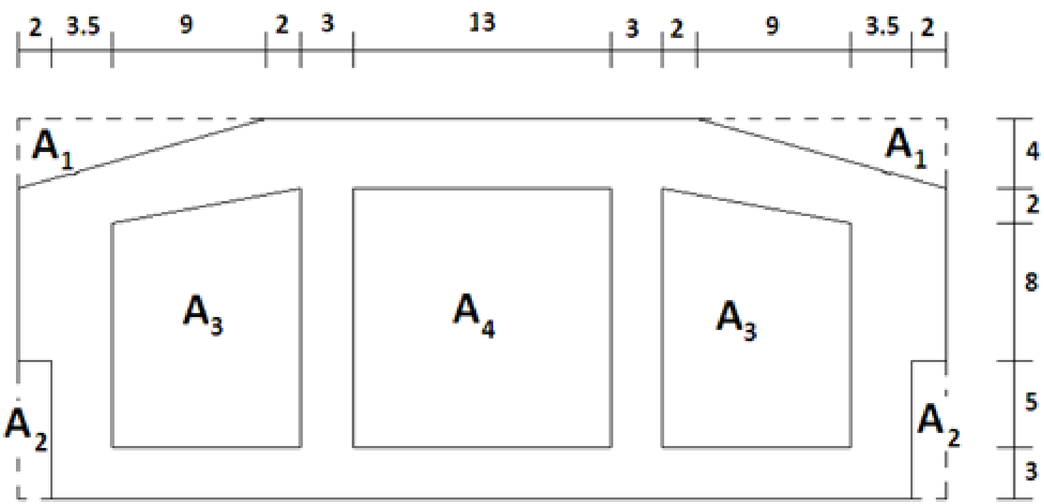


Fig.A.1. The size of the ribbed block (Unit: cm)

$A_{net} = A_{total} - 2 * A_1 - 2 * A_2 - 2 * A_3 - A_4$, where

$A_{Total} = 52cm * 22cm = 1144\ cm^2$ $A_1 = 0.5 * 14.5cm * 4cm = 29.0\ cm^2$, $A_2 = 2.0cm * 8.0cm = 16.0\ cm^2$ $A_3 = 0.5 * (15 + 13)cm * 11cm = 154cm^2$, $A_4 = 13cm * 15cm = 195\ cm^2$

$A_{net} = 1144\ cm^2 - 2 * 29cm^2 - 2 * 16cm^2 - 2 * 154\ cm^2 - 195cm^2 = 551cm^2$

A.2. Concrete Poured In the Precast Section

After placing of the precast block on the precast joist, concrete will be poured. The spacing between the center lines of consecutive ribs is 600 mm. Therefore, the concrete poured between the rib blocks has the following shapes:

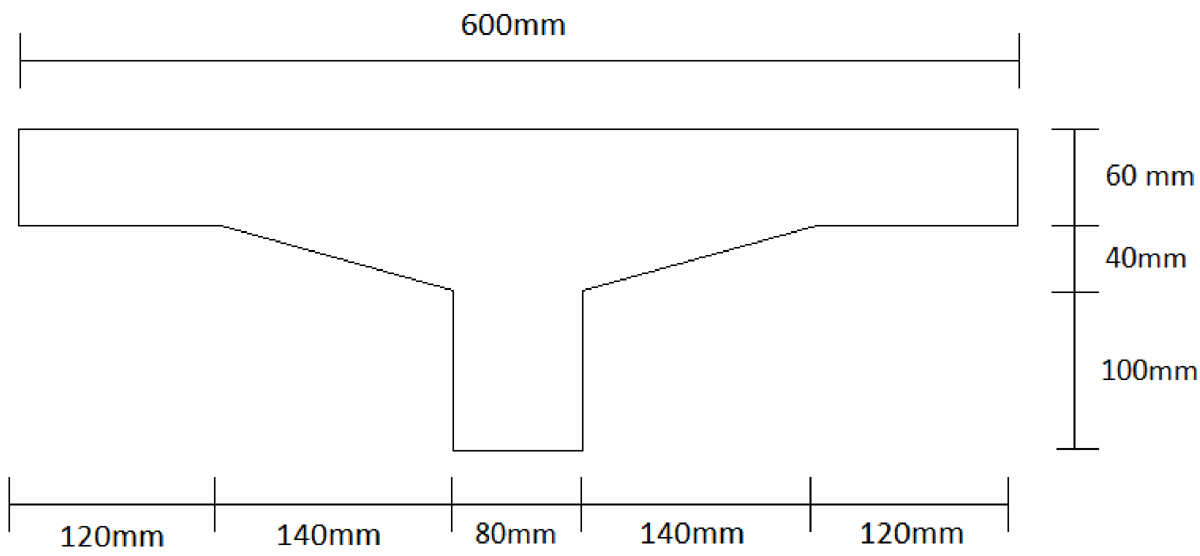


Fig.A.2. The cross-sectional size of the concrete between the ribbed block

X-sectional area of the concrete = (600*200) mm^2 - [(120*140)+(0.5*140*(100+140)]mm^2

=52800 mm^2

Appendix B. Shear Resistance of a Section

In this part the shear resistance of a section, in terms of the maximum line load resistance for a 5m span precast joist, with a stirrup arrangement of ϕ6 c/c 150 and ϕ8 c/c 150 is discussed according to EBCS – 2 1995, Sec. 4.5.3

For ϕ6 c/c 150,

$$V_s = \frac{A_v * d * f_{yd}}{S}$$

$$A_v = 2 * a_s = 2 * \left(\frac{\pi * 6^2}{4}\right) = 56.55\ mm^2$$

$$d = 280mm - \left(15 + 6 + \left(\frac{14}{2}\right)\right) mm = 252mm$$

$$f_{yd} = 260\ {}^{N}/_{mm^2}\ \&\quad S = 150\ mm$$

$$V_s = \frac{2 * a_s * f_{yd} * d}{S}$$

$$V_s = \frac{56.55\ mm^2 * 260.870\ {}^{N}/_{mm^2} * 252\ mm}{150\ mm} = 24.837\ kN$$

$$V_C = 0.25 * f_{ctd} * K_1 * K_2 * b_w * d$$

$$f_{ctd} = 1.031\ Mpa = 1.031\ {}^{N}/_{mm^2}$$

In addition to the top reinforcement in the precast joist, assume 2Φ14 reinforcement is provided at the supports, in addition to the reinforcement for in the precast section.

Therefore, take: $A_S = 2 * \pi * 7^2 + \pi * 4^2 = 358.14\ mm^2$

$$\rho = \frac{A_S}{b_w * d} = \frac{358.14\ mm^2}{120mm * 252mm} = 11.94 * 10^{-3}$$

$$K_1 = 1 + 50\rho = 1 + 50 * (11.94 * 10^{-3}) = 1.597 < 2.0$$

$$K_2 = 1.6 - d = 1.6 - 0.25 = 1.35 \geq 1.0$$

$V_C = 0.25 * 1.031\ {}^{N}/_{mm^2} * 1.597 * 1.35 * 80mm * 252mm = 11{,}20.00\ N$

$= 11.20kN$

$V_T = V_C + V_S = 11.20\ kN + 24.84\ kN = 36.04\ kN$

According to EBCS-2, 1995 the limiting value to avoid the diagonal compression failure is:

$V_{Rd} = 0.25 * f_{cd} * b_w * d = 0.25 * 11.33\ {}^{N}/_{mm^2} * 600mm * 253\ mm$

$= 429{,}973.5\ N$

=> $V_{Rd} = 429.97\ kN$

Therefore, the section is safe against diagonal compression failure.

$$V_{max} = \frac{w * l}{2}$$

$$=> \quad w = \frac{2 * V_{max}}{l} = \frac{2 * V_{max}}{5} = 0.4 * V_{max} = 0.4 * 36.04\frac{kN}{m} = 14.42\ kN/m$$

For ϕ8 c/c 150,

$$V_s = \frac{A_v * d * f_{yd}}{S}$$

$$A_v = 2 * a_s = 2 * \left(\frac{\pi * 8^2}{4}\right) = 100.53\ mm^2$$

$$d = 280mm - \left(15 + 8 + \left(\frac{14}{2}\right)\right) mm = 250mm$$

$f_{yd} = 260\ {}^{N}/_{mm^2}$ & $\quad S = 150\ mm$

$$V_s = \frac{2 * a_s * f_{yd} * d}{S}$$

$$V_s = \frac{100.53\, mm^2 * 260.870\, {}^{N}/_{mm^2} * 250\, mm}{150\, mm} = 43.710\, kN$$

$$V_C = 0.25 * f_{ctd} * K_1 * K_2 * b_w * d$$

$$f_{ctd} = 1.031\, Mpa = 1.031\, {}^{N}/_{mm^2}$$

In addition to the top reinforcement in the precast joist, assume 2Φ14 reinforcement is provided at the supports, in addition to the reinforcement for in the precast section.

Therefore, take: $A_S = 2 * \pi * 7^2 + \pi * 4^2 = 358.14\, mm^2$

$$\rho = \frac{A_S}{b_w * d} = \frac{358.14\, mm^2}{120mm * 250mm} = 11.94 * 10^{-3}$$

$$K_1 = 1 + 50\rho = 1 + 50 * (11.94 * 10^{-3}) = 1.597 < 2.0$$

$$K_2 = 1.6 - d = 1.6 - 0.25 = 1.35 \geq 1.0$$

$$V_C = 0.25 * 1.031\, {}^{N}/_{mm^2} * 1.597 * 1.35 * 80mm * 252mm = 11{,}20.00\, N$$

$$= 11.20kN$$

$$V_T = V_C + V_S = 11.20\, kN + 43.71\, kN = 54.91\, kN$$

According to EBCS-2, 1995 the limiting value to avoid the diagonal compression failure is:

$$V_{Rd} = 0.25 * f_{cd} * b_w * d = 0.25 * 11.33\, {}^{N}/_{mm^2} * 600mm * 253\, mm$$

$$= 429{,}973.5\, N$$

$$=> \quad V_{Rd} = 429.97\, kN$$

Therefore, the section is safe against diagonal compression failure.

$$V_{max} = \frac{w * l}{2}$$

$$=> \quad w = \frac{2 * V_{max}}{l} = \frac{2 * V_{max}}{5} = 0.4 * V_{max} = 0.4 * 54.91 \frac{kN}{m} = 21.96\, kN/m$$

Appendix C. Effect of Concrete in the Initial Stage

The precast concrete that surrounds the reinforcement is ignored in the analysis and design of the initial stage of construction, and the effect of the concrete is taken as a reserve. The purpose of this section is to study one specific model and to show the significant difference in ignoring the tension stiffening effect. The economical section with the tension stiffening effect is studied for both the ultimate limit state and serviceability limit state in the initial stage. This is done with two types of models. As a first model the same section in the fourth chapter is used. In the second model the effect of the concrete is considered by taking the concrete and the bottom reinforcement as a composite section and converting the composite section by an equivalent or transformed cross-sectional area by steel.

The aim of this study is to compare the conservative model, model 1, which has taken the precast concrete as a reserve and the unsafe model, model 2, which assumes the precast concrete as uncracked section in the initial stage.

Table C.1 and Table C.2 below summarizes the demand to capacity ratio and the maximum deflection of the two models, respectively.

C.1. ULTIMATE LIMIT STATE

Table C.1. The demand to capacity ratio of the critical members

Number of intermediate support	Position of reinforcement	Demand to capacity ratio	
		Model 1	Model 2
0	Top reinforcement	**5.10**	**4.37**
	Bottom reinforcement	0.66	0.30
	Stirrups	3.51	3.59
1	Top reinforcement	0.83	0.72
	Bottom reinforcement	0.26	0.24
	Stirrups	**2.05**	**2.00**
2	Top reinforcement	0.38	0.32
	Bottom reinforcement	0.11	0.10
	Stirrups	**1.25**	**1.19**
3	Top reinforcement	0.21	0.18
	Bottom reinforcement	0.07	0.07
	Stirrups	0.89	0.86

The ultimate limit state requirement is satisfied if the section has demand to capacity ratio less than one for the critical member of the precast joist. Therefore, three intermediate supports should be provided in order to have a safe section for ultimate limit state requirement.

C.2. SERVICEABILITY LIMIT STATE

Table C.2. The maximum deflection of each model

Number of intermediate support	Model 1	Model 2
0	58.1	45.7
1	2.9	2.5
2	0.8	0.7
3	0.4	0.3

The limiting values of deflection are specified in Table 3.2 and for both cases one intermediate support should be provided in order to satisfy the serviceability limit state requirement of the precast joist.

Therefore, three intermediate temporary supports are required to satisfy both the Serviceability and Ultimate Limit State requirement of the precast joist.

For the specific example above the concrete effect is not significant and in a similar manner, this indirect approach for checking the concrete role in the precast joist can be implemented to the other models in this thesis.

C.3. STRESS STRAIN DIAGRAM

The above preliminary analysis requires further investigation to study the effect of concrete in reinforced concrete structure. For this purpose the following section discusses the effect of concrete on the stress-strain diagram of steel reinforcement in reinforced concrete section and the stress-strain diagram of reinforced concrete section with the tension stiffening effect. During analysis the material property of the section should be modified to consider the effect of concrete in tension zone.

C.3.1. FOR STELL IN REINFORCED CONCRETE SECTION

When an axial load acts on steel bar surrounded by concrete, crack will form when the stress in the concrete exceeds the tension capacity of the concrete. Soon the crack forms the steel bar will carry all the stress in the section at the crack position and the stress in the steel decreases between the cracks, in which the difference will be carried by the concrete in tension. [15] Therefore, the stress –strain diagram of the steel in concrete and steel out of concrete has difference as shown in the figure below.

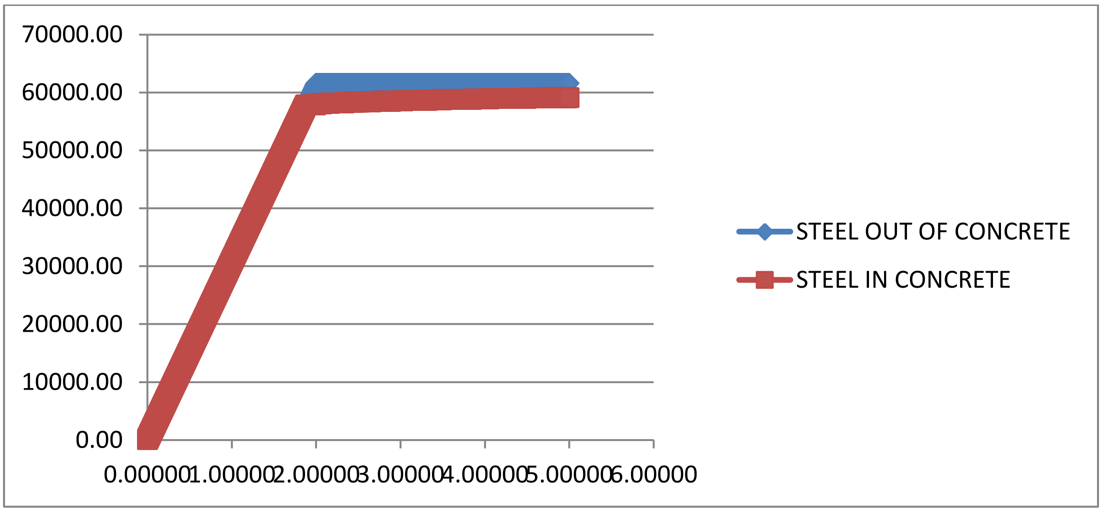


Fig. C.1. The stress-strain diagram of steel bar

C.3.2. FOR REINFORCED CONCRETE SECTION WITH TENSION STIFFENING EFFECT

For loads slightly above the cracking load, a significant fraction of tensile force between cracks is in the concrete, and hence the member behaves more like an uncracked section than cracked section. As the loads are increased, internal cracking occurs, with the result that the steel strains increase with no significant change in the tensile force in the concrete. At very high load, the tensile force in the concrete is insignificant compared with that in the steel, and the member approximates a completely cracked section. The effect of the tensile force in the concrete on EI is referred to as *tension stiffening*. [9]

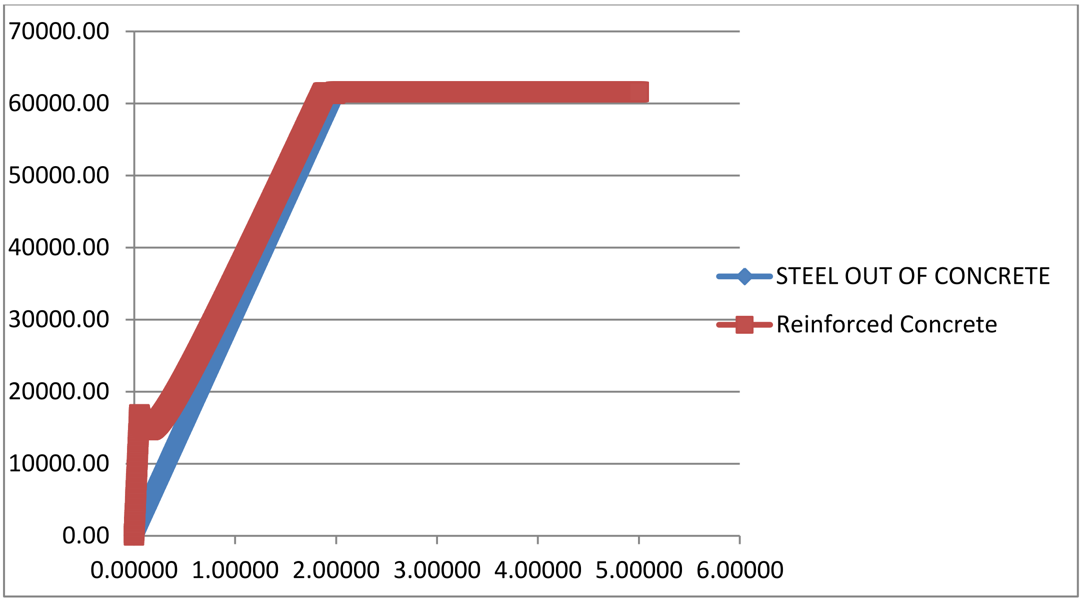


Fig. C.2. The stress-strain diagram of Reinforced concrete section

Appendix D. Precast Joist with Smaller Section Size

For the purpose of comparison one single model is prepared by decreasing the height of the model shown in Fig.4.1 from 240mm to 160mm, for the following arrangement of reinforcement, top longitudinal reinforcement 1ϕ8, bottom longitudinal reinforcement 2ϕ12 and shear reinforcement of ϕ6 c/c 150. Both the demand to capacity ratio and the deflection is calculated as shown in the table below.

Table D.1. The demand to capacity ratio of the critical members and the maximum deflection of the model with h = 240mm

Height of the model is 240 mm					
Joint load	Position of reinforcement	Number of intermediate support			
		0	1	2	3
0.266 kN	Top reinforcement (1ϕ8)	5.10	0.83	0.38	0.21
	Bottom reinforcement (2ϕ12)	0.66	0.26	0.11	0.07
	Stirrups (ϕ6 c/c 150)	3.51	2.05	1.25	0.89
Failure mode		Buckling of top reinforcement	Buckling of Stirrup	Buckling of Stirrup	*
Deflection		56.70	2.80	0.80	0.40

* The system is safe against the maximum expected load on the structure.

Table D.2. The demand to capacity ratio of the critical members and the maximum deflection of the model with h = 160mm

Height of the model is 160 mm					
Joint load	Position of reinforcement	Number of intermediate support			
		0	1	2	3
0.266 kN	Top reinforcement (1ϕ8)	8.003	1.261	0.575	0.309
	Bottom reinforcement (2ϕ12)	1.073	0.373	0.142	0.088
	Stirrups (ϕ6 c/c 150)	1.979	1.194	0.727	0.524
Failure mode		Buckling of top reinforcement	Buckling of top reinforcement	*	*
Deflection		135.7	5.1	1.2	0.4

* The system is safe against the maximum expected load on the structure.

From the results in the above tables, it is possible to conclude that, the system safety increases as the height of section decreases for Ultimate Limit State and the deflection increases as the model height decreases. For both the above cases the number of temporary intermediate support required to satisfy deflection requirement for serviceability limit state is only one. In general, the requirement of number of temporary intermediate support in the initial stage decreases as the height of the model in the initial stage decreases. However, the depth requirement in the final stage should also be considered in the design process.

The minimum depth of the model in the initial stage is calculated by deducting the concrete cover from the effective depth required in the final stage, to satisfy deflection requirement for serviceability limit state in the final stage. Since the minimum effective depth required in the final stage is 208.33 mm, as calculated in section 3.2.2, the minimum depth in the initial stage is h = 208.33 mm + 15 mm =

223.33 mm. Therefore, the above model, with h = 160 mm, ***does not satisfy the deflection requirement*** for serviceability limit state in the final stage.

To satisfy the deflection requirement the effective length should be less than 5m, and it can be calculated as follows using equation (3.6):

For f_{yk} = 400Mpa, $$d = \left[0.4 + 0.6 * {f_{yk}}/{400}\right] * {L_e}/{\beta_a} = {L_e}/{\beta_a}$$

$$=> \quad \mathrm{L_e} = \mathrm{d} * \beta_a = (160mm - 15mm) * 24 = 3480mm$$

The model prepared above is to show the effect of the change in geometry for the precast joist.

Appendix E. Design Chart

For the design of the precast joist in the final stage of construction the design chart, according to EBCS-2, 1995, is prepared in table format, using the design equations as follows:

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.000	0.000	0.000	0.000	0.000	10.0	0.00	0.000	0.000	1.000	10.000	0.000	0.000	0.000	0.000
0.000	0.005	0.003	0.033	0.000	10.0	-0.10	0.010	0.099	0.997	9.967	0.405	0.910	1.415	1.920
0.002	0.019	0.007	0.066	0.002	10.0	-0.20	0.020	0.196	0.993	9.934	0.310	0.820	1.330	1.840
0.004	0.042	0.010	0.098	0.004	10.0	-0.30	0.029	0.291	0.990	9.902	0.215	0.730	1.245	1.760
0.007	0.072	0.013	0.130	0.007	10.0	-0.40	0.038	0.385	0.987	9.870	0.120	0.640	1.160	1.680
0.011	0.109	0.016	0.162	0.011	10.0	-0.50	0.048	0.476	0.984	9.838	0.025	0.550	1.075	1.600
0.015	0.153	0.019	0.194	0.015	10.0	-0.60	0.057	0.566	0.981	9.806	-0.070	0.460	0.990	1.520
0.020	0.202	0.023	0.225	0.020	10.0	-0.70	0.065	0.654	0.977	9.775	-0.165	0.370	0.905	1.440
0.026	0.257	0.026	0.256	0.025	10.0	-0.80	0.074	0.741	0.974	9.744	-0.260	0.280	0.820	1.360
0.032	0.316	0.029	0.287	0.031	10.0	-0.90	0.083	0.826	0.971	9.713	-0.355	0.190	0.735	1.280
0.038	0.379	0.032	0.318	0.037	10.0	-1.00	0.091	0.909	0.968	9.682	-0.450	0.100	0.650	1.200

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.045	0.445	0.035	0.349	0.043	10.0	-1.10	0.099	0.991	0.965	9.651	-0.545	0.010	0.565	1.120
0.051	0.514	0.038	0.379	0.049	10.0	-1.20	0.107	1.071	0.962	9.621	-0.640	-0.080	0.480	1.040
0.059	0.586	0.041	0.410	0.056	10.0	-1.30	0.115	1.150	0.959	9.590	-0.735	-0.170	0.395	0.960
0.066	0.659	0.044	0.441	0.063	10.0	-1.40	0.123	1.228	0.956	9.559	-0.830	-0.260	0.310	0.880
0.073	0.734	0.047	0.471	0.070	10.0	-1.50	0.130	1.304	0.953	9.529	-0.925	-0.350	0.225	0.800
0.081	0.809	0.050	0.502	0.077	10.0	-1.60	0.138	1.379	0.950	9.498	-1.020	-0.440	0.140	0.720
0.089	0.885	0.053	0.532	0.084	10.0	-1.70	0.145	1.453	0.947	9.468	-1.115	-0.530	0.055	0.640
0.096	0.961	0.056	0.563	0.091	10.0	-1.80	0.153	1.525	0.944	9.437	-1.210	-0.620	-0.030	0.560
0.104	1.036	0.059	0.594	0.097	10.0	-1.90	0.160	1.597	0.941	9.406	-1.305	-0.710	-0.115	0.480
0.111	1.111	0.063	0.625	0.104	10.0	-2.00	0.167	1.667	0.938	9.375	-1.400	-0.800	-0.200	0.400
0.118	1.185	0.066	0.656	0.111	10.0	-2.10	0.174	1.736	0.934	9.344	-1.495	-0.890	-0.285	0.320
0.126	1.257	0.069	0.688	0.117	10.0	-2.20	0.180	1.803	0.931	9.312	-1.590	-0.980	-0.370	0.240
0.133	1.328	0.072	0.719	0.123	10.0	-2.30	0.187	1.870	0.928	9.281	-1.685	-1.070	-0.455	0.160
0.140	1.398	0.075	0.751	0.129	10.0	-2.40	0.194	1.935	0.925	9.249	-1.780	-1.160	-0.540	0.080
0.147	1.467	0.078	0.782	0.135	10.0	-2.50	0.200	2.000	0.922	9.218	-1.875	-1.250	-0.625	0.000

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.153	1.534	0.081	0.813	0.141	10.0	-2.60	0.206	2.063	0.919	9.187	-1.970	-1.340	-0.710	-0.080
0.160	1.601	0.084	0.844	0.147	10.0	-2.70	0.213	2.126	0.916	9.156	-2.065	-1.430	-0.795	-0.160
0.167	1.667	0.087	0.874	0.152	10.0	-2.80	0.219	2.188	0.913	9.126	-2.160	-1.520	-0.880	-0.240
0.173	1.731	0.090	0.904	0.157	10.0	-2.90	0.225	2.248	0.910	9.096	-2.255	-1.610	-0.965	-0.320
0.179	1.795	0.093	0.934	0.163	10.0	-3.00	0.231	2.308	0.907	9.066	-2.350	-1.700	-1.050	-0.400
0.186	1.858	0.096	0.964	0.168	10.0	-3.10	0.237	2.366	0.904	9.036	-2.445	-1.790	-1.135	-0.480
0.192	1.919	0.099	0.993	0.173	10.0	-3.20	0.242	2.424	0.901	9.007	-2.540	-1.880	-1.220	-0.560
0.198	1.980	0.102	1.022	0.178	10.0	-3.30	0.248	2.481	0.898	8.978	-2.635	-1.970	-1.305	-0.640
0.204	2.040	0.105	1.050	0.183	10.0	-3.40	0.254	2.537	0.895	8.950	-2.730	-2.060	-1.390	-0.720
0.209	2.093	0.108	1.076	0.187	10.0	-3.49	0.259	2.587	0.892	8.924	-2.816	-2.141	-1.467	-0.792
0.210	2.099	0.108	1.078	0.187	10.0	-3.50	0.259	2.593	0.892	8.922	-2.825	-2.150	-1.475	-0.800
0.211	2.114	0.109	1.086	0.188	9.90	-3.50	0.261	2.612	0.891	8.914	-2.830	-2.160	-1.490	-0.820
0.213	2.130	0.109	1.095	0.190	9.80	-3.50	0.263	2.632	0.891	8.905	-2.835	-2.170	-1.505	-0.840
0.215	2.146	0.110	1.103	0.191	9.70	-3.50	0.265	2.652	0.890	8.897	-2.840	-2.180	-1.520	-0.860
0.216	2.163	0.111	1.111	0.192	9.60	-3.50	0.267	2.672	0.889	8.889	-2.845	-2.190	-1.535	-0.880

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.218	2.179	0.112	1.120	0.194	9.50	-3.50	0.269	2.692	0.888	8.880	-2.850	-2.200	-1.550	-0.900
0.220	2.196	0.113	1.129	0.195	9.40	-3.50	0.271	2.713	0.887	8.871	-2.855	-2.210	-1.565	-0.920
0.221	2.214	0.114	1.137	0.196	9.30	-3.50	0.273	2.734	0.886	8.863	-2.860	-2.220	-1.580	-0.940
0.223	2.231	0.115	1.146	0.198	9.20	-3.50	0.276	2.756	0.885	8.854	-2.865	-2.230	-1.595	-0.960
0.225	2.249	0.116	1.155	0.199	9.10	-3.50	0.278	2.778	0.884	8.845	-2.870	-2.240	-1.610	-0.980
0.227	2.267	0.116	1.165	0.200	9.00	-3.50	0.280	2.800	0.884	8.835	-2.875	-2.250	-1.625	-1.000
0.236	2.361	0.121	1.213	0.207	8.50	-3.50	0.292	2.917	0.879	8.787	-2.900	-2.300	-1.700	-1.100
0.230	2.304	0.118	1.184	0.203	8.80	-3.50	0.285	2.846	0.882	8.816	-2.885	-2.270	-1.655	-1.040
0.232	2.322	0.119	1.193	0.205	8.70	-3.50	0.287	2.869	0.881	8.807	-2.890	-2.280	-1.670	-1.060
0.234	2.342	0.120	1.203	0.206	8.60	-3.50	0.289	2.893	0.880	8.797	-2.895	-2.290	-1.685	-1.080
0.236	2.361	0.121	1.213	0.207	8.50	-3.50	0.292	2.917	0.879	8.787	-2.900	-2.300	-1.700	-1.100
0.238	2.381	0.122	1.223	0.209	8.40	-3.50	0.294	2.941	0.878	8.777	-2.905	-2.310	-1.715	-1.120
0.240	2.401	0.123	1.234	0.210	8.30	-3.50	0.297	2.966	0.877	8.766	-2.910	-2.320	-1.730	-1.140
0.242	2.422	0.124	1.244	0.212	8.20	-3.50	0.299	2.991	0.876	8.756	-2.915	-2.330	-1.745	-1.160
0.244	2.443	0.126	1.255	0.214	8.10	-3.50	0.302	3.017	0.874	8.745	-2.920	-2.340	-1.760	-1.180

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.246	2.464	0.127	1.266	0.215	8.00	-3.50	0.304	3.043	0.873	8.734	-2.925	-2.350	-1.775	-1.200
0.249	2.485	0.128	1.277	0.217	7.90	-3.50	0.307	3.070	0.872	8.723	-2.930	-2.360	-1.790	-1.220
0.251	2.507	0.129	1.288	0.218	7.80	-3.50	0.310	3.097	0.871	8.712	-2.935	-2.370	-1.805	-1.240
0.253	2.530	0.130	1.300	0.220	7.70	-3.50	0.313	3.125	0.870	8.700	-2.940	-2.380	-1.820	-1.260
0.255	2.553	0.131	1.312	0.222	7.60	-3.50	0.315	3.153	0.869	8.688	-2.945	-2.390	-1.835	-1.280
0.258	2.576	0.132	1.324	0.223	7.50	-3.50	0.318	3.182	0.868	8.676	-2.950	-2.400	-1.850	-1.300
0.260	2.599	0.134	1.336	0.225	7.40	-3.50	0.321	3.211	0.866	8.664	-2.955	-2.410	-1.865	-1.320
0.262	2.623	0.135	1.348	0.227	7.30	-3.50	0.324	3.241	0.865	8.652	-2.960	-2.420	-1.880	-1.340
0.265	2.648	0.136	1.361	0.229	7.20	-3.50	0.327	3.271	0.864	8.639	-2.965	-2.430	-1.895	-1.360
0.267	2.673	0.137	1.373	0.231	7.10	-3.50	0.330	3.302	0.863	8.627	-2.970	-2.440	-1.910	-1.380
0.270	2.698	0.139	1.387	0.232	7.00	-3.50	0.333	3.333	0.861	8.613	-2.975	-2.450	-1.925	-1.400
0.272	2.724	0.140	1.400	0.234	6.90	-3.50	0.337	3.365	0.860	8.600	-2.980	-2.460	-1.940	-1.420
0.275	2.751	0.141	1.413	0.236	6.80	-3.50	0.340	3.398	0.859	8.587	-2.985	-2.470	-1.955	-1.440
0.278	2.778	0.143	1.427	0.238	6.70	-3.50	0.343	3.431	0.857	8.573	-2.990	-2.480	-1.970	-1.460
0.281	2.805	0.144	1.441	0.240	6.60	-3.50	0.347	3.465	0.856	8.559	-2.995	-2.490	-1.985	-1.480

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.283	2.833	0.146	1.456	0.242	6.50	-3.50	0.350	3.500	0.854	8.544	-3.000	-2.500	-2.000	-1.500
0.286	2.862	0.147	1.471	0.244	6.40	-3.50	0.354	3.535	0.853	8.529	-3.005	-2.510	-2.015	-1.520
0.289	2.891	0.149	1.486	0.246	6.30	-3.50	0.357	3.571	0.851	8.514	-3.010	-2.520	-2.030	-1.540
0.292	2.921	0.150	1.501	0.248	6.20	-3.50	0.361	3.608	0.850	8.499	-3.015	-2.530	-2.045	-1.560
0.295	2.951	0.152	1.517	0.250	6.10	-3.50	0.365	3.646	0.848	8.483	-3.020	-2.540	-2.060	-1.580
0.298	2.982	0.153	1.533	0.253	6.00	-3.50	0.368	3.684	0.847	8.467	-3.025	-2.550	-2.075	-1.600
0.301	3.014	0.155	1.549	0.255	5.90	-3.50	0.372	3.723	0.845	8.451	-3.030	-2.560	-2.090	-1.620
0.305	3.047	0.157	1.565	0.257	5.80	-3.50	0.376	3.763	0.843	8.435	-3.035	-2.570	-2.105	-1.640
0.308	3.080	0.158	1.582	0.259	5.70	-3.50	0.380	3.804	0.842	8.418	-3.040	-2.580	-2.120	-1.660
0.311	3.114	0.160	1.600	0.262	5.60	-3.50	0.385	3.846	0.840	8.400	-3.045	-2.590	-2.135	-1.680
0.315	3.148	0.162	1.618	0.264	5.50	-3.50	0.389	3.889	0.838	8.382	-3.050	-2.600	-2.150	-1.700
0.318	3.184	0.164	1.636	0.266	5.40	-3.50	0.393	3.933	0.836	8.364	-3.055	-2.610	-2.165	-1.720
0.322	3.220	0.165	1.654	0.269	5.30	-3.50	0.398	3.977	0.835	8.346	-3.060	-2.620	-2.180	-1.740
0.326	3.257	0.167	1.673	0.271	5.20	-3.50	0.402	4.023	0.833	8.327	-3.065	-2.630	-2.195	-1.760
0.329	3.295	0.169	1.693	0.274	5.10	-3.50	0.407	4.070	0.831	8.307	-3.070	-2.640	-2.210	-1.780

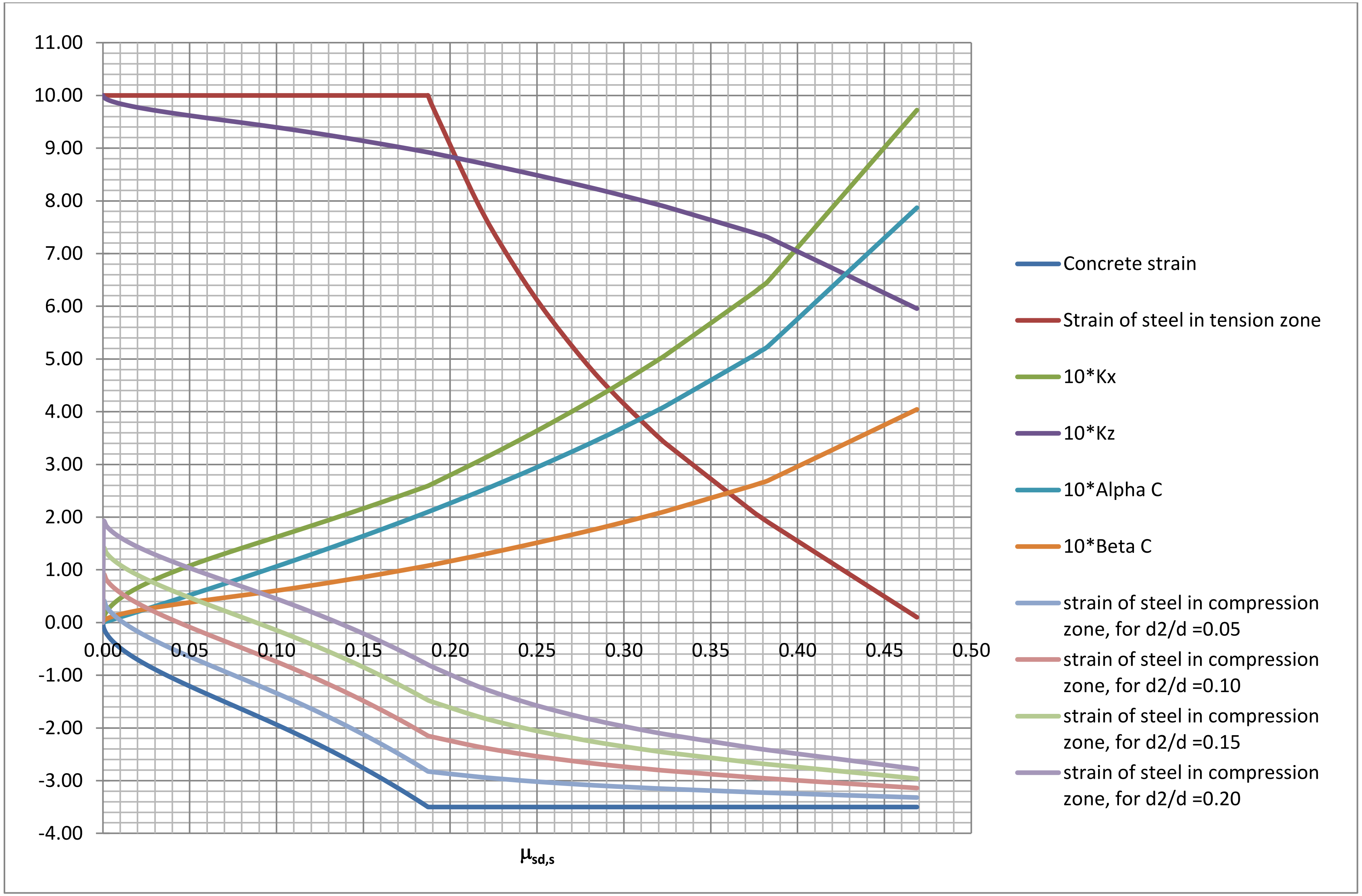
											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.333	3.333	0.171	1.713	0.276	5.00	-3.50	0.412	4.118	0.829	8.287	-3.075	-2.650	-2.225	-1.800
0.337	3.373	0.173	1.733	0.279	4.90	-3.50	0.417	4.167	0.827	8.267	-3.080	-2.660	-2.240	-1.820
0.341	3.414	0.175	1.754	0.281	4.80	-3.50	0.422	4.217	0.825	8.246	-3.085	-2.670	-2.255	-1.840
0.346	3.455	0.178	1.775	0.284	4.70	-3.50	0.427	4.268	0.822	8.225	-3.090	-2.680	-2.270	-1.860
0.350	3.498	0.180	1.797	0.287	4.60	-3.50	0.432	4.321	0.820	8.203	-3.095	-2.690	-2.285	-1.880
0.354	3.542	0.182	1.820	0.290	4.50	-3.50	0.437	4.375	0.818	8.180	-3.100	-2.700	-2.300	-1.900
0.359	3.586	0.184	1.843	0.293	4.40	-3.50	0.443	4.430	0.816	8.157	-3.105	-2.710	-2.315	-1.920
0.363	3.632	0.187	1.867	0.295	4.30	-3.50	0.449	4.487	0.813	8.133	-3.110	-2.720	-2.330	-1.940
0.368	3.680	0.189	1.891	0.298	4.20	-3.50	0.455	4.545	0.811	8.109	-3.115	-2.730	-2.345	-1.960
0.373	3.728	0.192	1.916	0.301	4.10	-3.50	0.461	4.605	0.808	8.084	-3.120	-2.740	-2.360	-1.980
0.378	3.778	0.194	1.941	0.304	4.00	-3.50	0.467	4.667	0.806	8.059	-3.125	-2.750	-2.375	-2.000
0.383	3.829	0.197	1.967	0.308	3.90	-3.50	0.473	4.730	0.803	8.033	-3.130	-2.760	-2.390	-2.020
0.388	3.881	0.199	1.994	0.311	3.80	-3.50	0.479	4.795	0.801	8.006	-3.135	-2.770	-2.405	-2.040
0.394	3.935	0.202	2.022	0.314	3.70	-3.50	0.486	4.861	0.798	7.978	-3.140	-2.780	-2.420	-2.060
0.399	3.991	0.205	2.051	0.317	3.60	-3.50	0.493	4.930	0.795	7.949	-3.145	-2.790	-2.435	-2.080

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.405	4.048	0.208	2.080	0.321	3.50	-3.50	0.500	5.000	0.792	7.920	-3.150	-2.800	-2.450	-2.100
0.411	4.106	0.211	2.110	0.324	3.40	-3.50	0.507	5.072	0.789	7.890	-3.155	-2.810	-2.465	-2.120
0.417	4.167	0.214	2.141	0.327	3.30	-3.50	0.515	5.147	0.786	7.859	-3.160	-2.820	-2.480	-2.140
0.423	4.229	0.217	2.173	0.331	3.20	-3.50	0.522	5.224	0.783	7.827	-3.165	-2.830	-2.495	-2.160
0.429	4.293	0.221	2.206	0.335	3.10	-3.50	0.530	5.303	0.779	7.794	-3.170	-2.840	-2.510	-2.180
0.436	4.359	0.224	2.240	0.338	3.00	-3.50	0.538	5.385	0.776	7.760	-3.175	-2.850	-2.525	-2.200
0.443	4.427	0.227	2.275	0.342	2.90	-3.50	0.547	5.469	0.773	7.725	-3.180	-2.860	-2.540	-2.220
0.450	4.497	0.231	2.311	0.346	2.80	-3.50	0.556	5.556	0.769	7.689	-3.185	-2.870	-2.555	-2.240
0.457	4.570	0.235	2.348	0.350	2.70	-3.50	0.565	5.645	0.765	7.652	-3.190	-2.880	-2.570	-2.260
0.464	4.645	0.239	2.387	0.354	2.60	-3.50	0.574	5.738	0.761	7.613	-3.195	-2.890	-2.585	-2.280
0.472	4.722	0.243	2.426	0.358	2.50	-3.50	0.583	5.833	0.757	7.574	-3.200	-2.900	-2.600	-2.300
0.480	4.802	0.247	2.468	0.362	2.40	-3.50	0.593	5.932	0.753	7.532	-3.205	-2.910	-2.615	-2.320
0.489	4.885	0.251	2.510	0.366	2.30	-3.50	0.603	6.034	0.749	7.490	-3.210	-2.920	-2.630	-2.340
0.497	4.971	0.255	2.554	0.370	2.20	-3.50	0.614	6.140	0.745	7.446	-3.215	-2.930	-2.645	-2.360
0.506	5.060	0.260	2.600	0.374	2.10	-3.50	0.625	6.250	0.740	7.400	-3.220	-2.940	-2.660	-2.380

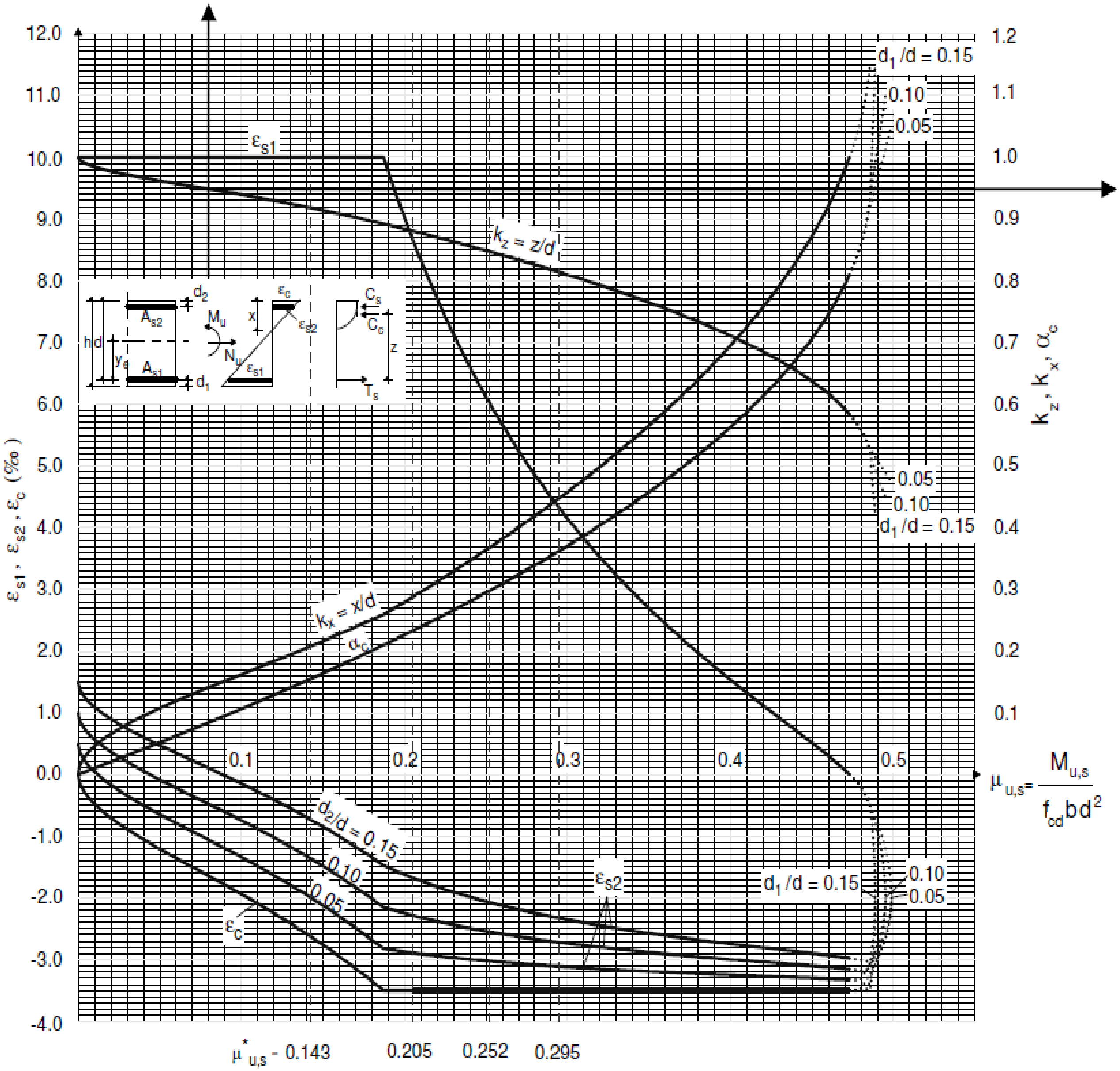
											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10{*}\alpha_C$	β_C	$10{*}\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10{*}K_x$	K_Z	$10{*}K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.515	5.152	0.265	2.647	0.379	2.00	-3.50	0.636	6.364	0.735	7.353	-3.225	-2.950	-2.675	-2.400
0.525	5.247	0.270	2.696	0.383	1.90	-3.50	0.648	6.481	0.730	7.304	-3.230	-2.960	-2.690	-2.420
0.535	5.346	0.275	2.747	0.388	1.80	-3.50	0.660	6.604	0.725	7.253	-3.235	-2.970	-2.705	-2.440
0.545	5.449	0.280	2.800	0.392	1.70	-3.50	0.673	6.731	0.720	7.200	-3.240	-2.980	-2.720	-2.460
0.556	5.556	0.285	2.855	0.397	1.60	-3.50	0.686	6.863	0.715	7.145	-3.245	-2.990	-2.735	-2.480
0.567	5.667	0.291	2.912	0.402	1.50	-3.50	0.700	7.000	0.709	7.088	-3.250	-3.000	-2.750	-2.500
0.578	5.782	0.297	2.971	0.406	1.40	-3.50	0.714	7.143	0.703	7.029	-3.255	-3.010	-2.765	-2.520
0.590	5.903	0.303	3.033	0.411	1.30	-3.50	0.729	7.292	0.697	6.967	-3.260	-3.020	-2.780	-2.540
0.603	6.028	0.310	3.098	0.416	1.20	-3.50	0.745	7.447	0.690	6.902	-3.265	-3.030	-2.795	-2.560
0.616	6.159	0.316	3.165	0.421	1.10	-3.50	0.761	7.609	0.684	6.835	-3.270	-3.040	-2.810	-2.580
0.630	6.296	0.324	3.235	0.426	1.00	-3.50	0.778	7.778	0.676	6.765	-3.275	-3.050	-2.825	-2.600
0.644	6.439	0.331	3.309	0.431	0.90	-3.50	0.795	7.955	0.669	6.691	-3.280	-3.060	-2.840	-2.620
0.659	6.589	0.339	3.386	0.436	0.80	-3.50	0.814	8.140	0.661	6.614	-3.285	-3.070	-2.855	-2.640
0.675	6.746	0.347	3.466	0.441	0.70	-3.50	0.833	8.333	0.653	6.534	-3.290	-3.080	-2.870	-2.660
0.691	6.911	0.355	3.551	0.446	0.60	-3.50	0.854	8.537	0.645	6.449	-3.295	-3.090	-2.885	-2.680

											d_2/d			
											0.05	0.10	0.15	0.20
α_C	$10*\alpha_C$	β_C	$10*\beta_C$	μ_{sd}	ε_{s1} ($^0/_{00}$)	ε_{cm} ($^0/_{00}$)	K_x	$10*K_x$	K_Z	$10*K_Z$	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)	ε_{S2} ($^0/_{00}$)
0.708	7.083	0.364	3.640	0.451	0.50	-3.50	0.875	8.750	0.636	6.360	-3.300	-3.100	-2.900	-2.700
0.726	7.265	0.373	3.733	0.455	0.40	-3.50	0.897	8.974	0.627	6.267	-3.305	-3.110	-2.915	-2.720
0.746	7.456	0.383	3.831	0.460	0.30	-3.50	0.921	9.211	0.617	6.169	-3.310	-3.120	-2.930	-2.740
0.766	7.658	0.393	3.935	0.464	0.20	-3.50	0.946	9.459	0.607	6.065	-3.315	-3.130	-2.945	-2.760
0.787	7.870	0.404	4.044	0.469	0.10	-3.50	0.972	9.722	0.596	5.956	-3.320	-3.140	-2.960	-2.780
0.810	8.095	0.416	4.160	0.473	0.00	-3.50	1.000	10.000	0.584	5.840	-3.325	-3.150	-2.975	-2.800

And the above values in the table can be presented in chart form as follows:


11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
$\mu_{sd,s}$
Concrete strain
Strain of steel in tension zone
10*Kx
10*Kz
10*Alpha C
10*Beta C
strain of steel in compression zone, for d2/d =0.05
strain of steel in compression zone, for d2/d =0.10
strain of steel in compression zone, for d2/d =0.15
strain of steel in compression zone, for d2/d =0.20

For comparison the design chart from EBCS-2, 1995 is:



DECLARATION

I, the undersigned, declare that the thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for the thesis have been duly acknowledged.

Name: SOPHONYAS ASRAT

Signature: ______________

Place: Addis Ababa institute of Technology

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Date of submission: June, 2013