Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 4, Issue 3; April-June, 2017, pp. 177-183
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http://www.krishisanskriti.org/Publication.html

Comparative Study of Earthquake Resistant Cast-in-Situ and Precast Concrete Building

Sai Samanth. A[1], Parool Priya[2], Dawood Lanker[3] and Kaushik Raj[4]

[1,2,3,4]*Department of Civil Engineering Manipal Institute of Technology*
E-mail: [1]samanth.anuma@gmail.com, [2]parool95priya@gmail.com
[3]dawood.lanker@gmail.com, [4]dawood.lanker@gmail.com

Abstract—*In the present scenario, due to growing urbanization, there have been various innovations in the construction industry leading to modernization of the implementation methodology in the conventional process of construction and selection of materials. Precast building construction is still in its nascent stages in India and thus there is a lack of awareness among the builders. This project seeks to make a comparative analysis of a multi-storeyed earthquake resistant cast-in situ and precast building. The framed structures were analyzed and designed using ETABS. Various aspects like storey displacement, storey drift, storey shear and base shear were computed and compared for cast-in situ and precast structures. The structures were then evaluated and compared for the quantity of steel and concrete.*

1. INTRODUCTION

The conventional or cast in situ concrete is a type of concrete which is produced by casting it into a mold or form and then curing it in uncontrolled environment at the construction site.

Precast Concrete is a type of concrete which is produced by casting it into mold or form, cured in controlled environment, transported to the construction site and then placed. Precast Concrete can be properly cured and closely monitored in the controlled environment of the precast plant. It is generally cast and cured on the ground level, thus providing more security. Moreover the forms or molds used in precast plant can be reused many times often making it cheaper than the cast in situ concrete in terms of cost of formwork.

Precast concrete construction is quick as it can be installed immediately as there is no waiting for it to gain strength after placing on site. It requires less labour without any need for specialized skills. However it requires special equipment for lifting and placing.

Moreover the span or size of the precast members is limited due to transportation difficulties. With cast in situ concrete, flexibility can be achieved in geometric shapes whereas precast concrete often comes in standard geometric shapes. With conventional concrete, it is easier to make last minute changes to structure. Cast in situ concrete structures are monolithic without any difficulties in connections unlike precast concrete.

In cast in situ concrete works, there's a possibility of reduction in strength and durability due to extreme temperatures, humidity whereas precast concrete is produced under strict quality control measures in the factory.

It has been found that the selective use of precast concrete within conventional building system may have economic advantages. One may think about using precast, but due to lack of awareness and limited availability its use hasn't picked up in India.

2. OBJECTIVE

The main objective of this project is to make a comparative analysis of a G+3 Storey (KEF MIT R&D lab) earthquake resistant reinforced concrete building using conventional or cast in situ concrete and precast concrete in terms of quantity of materials. Further the two models are compared for storey drift, storey displacement, storey shear and base shear. The G+3 storey building has been analyzed using ETABS.

3. CONSIDERATIONS

3.1. Material Data

i. Concrete: M25 grade for conventional and precast building

: M60 and M15 grade for precast slabs

ii. Steel : Fe 500 grade

:Pre-stressing tendons of 1500 MPa characteristic strength

iii. Brick Masonry of unit weight 21 KN/mm^3

iv. Filling (Cinder) of unit weight 7.85 KN/mm^3

3.2. Building Data

i. Plan Dimension : 19m x 22 m

ii. Typical Storey height : 3.6 m

iii. Number of stories : 4 (G+3)

iv. Wall : Periphery 160 mm thick

: Partition 150 mm thick

: Lift 200 mm thick

: Shear 160 mm thick

3.3. Earthquake Data

: Zone V

: Type II soil

: Importance Factor 1

: Response Reduction Factor 3

3.4. Loads

i. Live Load (As per - IS 875 Part II) :

: Corridors, passages, lobbies – 4 KN/m2

: Operating rooms, laboratories – 3 KN/m2

: Lounges, toilets and bathrooms – 2 KN/m2

: Staff rooms, office rooms – 2.5 KN/m2

: Flat roof with access – 1.5 KN/m2

ii. Dead Load (As per - IS 875 Part I) :

: Floor finish 1 KN/m2

: Water proofing 1.5 KN/m2

: Sunk Load for indoor garden considering soil density of 18 KN/m and sunk of 300mm is given by the product of density and sunk depth as

$18 \times 0.3 = 5.4$ KN/m2

iii. Earthquake Load : In X and Y direction

3.5. Load combinations

DL + LL

DL + Eqx

DL – Eqx

DL + Eqy

DL – Eqy

DL + 0.8LL + 0.8EQx

DL + 0.8LL - 0.8EQx

DL + 0.8LL + 0.8EQy

DL + 0.8LL - 0.8EQy

1.5(DL + LL)

1.5(DL + EQx)

1.5(DL -EQx)

1.5(DL + EQy)

1.5(DL - EQy)

1.2(DL + LL + EQx)

1.2(DL + LL - EQx)

1.2(DL + LL + EQy)

1.2(DL + LL - EQy)

0.9DL + 1.5EQx

0.9DL - 1.5EQx

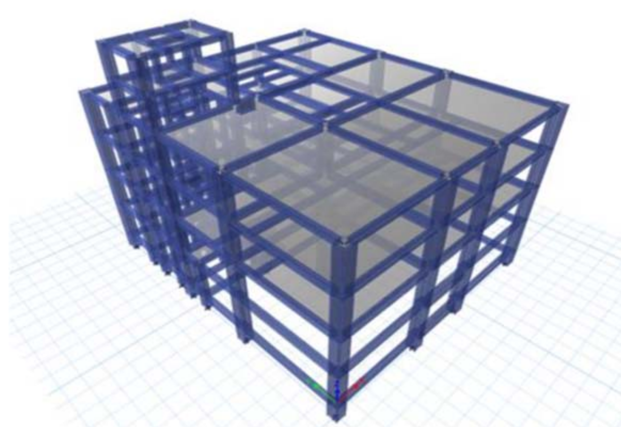
0.9DL + 1.5EQx

0.9DL - 1.5EQx

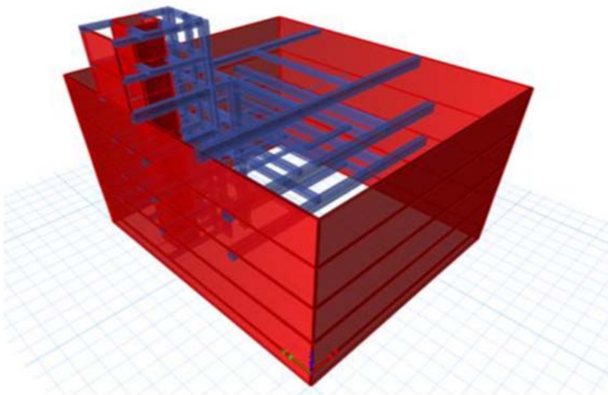
ENVELOPE(program determined)

4. METHODOLOGY

The project consists of the comparative analysis of KEF R&D Centre which is a precast concrete structure. Since it is a precast structure, the framing plan was modified accordingly to suit the requirements of the conventional design. The first step was to prepare the framing plan of each floor of the structure in AutoCAD which was imported to ETABS for the purpose of analysis and design. Various sections and materials were defined and assigned, loads were applied and loading cases defined according to relevant Indian Standard Codes. Then the structure was analyzed and structural elements viz. beams and columns were designed using ETABS. Further slabs, stairs and foundations were manually designed and manual checks for the design of columns, beams and base shear were performed in Microsoft Excel. Further, the conventional ETABS model was modified as a precast model. In addition to the conventional elements, precast walls and composite slabs were designed.



Cast in situ model.



Pre cast model.

5. EVALUATION

Storey is the space between two adjacent floors and drift is defined as the lateral displacement, so storey drift is the drift of one level of a multi-storey building relative to the level above or below it. Storey drift is directly related to stiffness of the structure. Higher stiffness implies lower drift and higher lateral loads on the structure. The storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the storey height. The greater the drift, greater is the extent or likelihood of damage.

Storey displacement is the drift or lateral displacement of one storey or level of the multi-storey building relative to the base.

Base shear is an estimate of the maximum expected lateral force that is expected to occur due to seismic ground motion at the base of the structure. Deign seismic base shear is the total design lateral force at the base of a structure. Calculations of base shear depend on the soil condition of the site, proximity to potential sources of seismic activity.

Storey shear is the sum of design lateral forces at all levels above the storey under consideration. Base shear is the sum of the storey shear of the entire building.

After the analysis and design of both the structures, the following evaluations and comparisons were made:

i. Quantity of concrete and steel: The quantity of concrete and steel required for the structural elements of the conventional model viz. slabs, beams, columns, staircase and footings were compared with the quantity of concrete required for composite slabs, beams, columns, walls, staircase and footings of the precast model.

ii. Storey drift and storey shear:

The storey drift and storey shear at all storey levels of the conventional model and the precast models were compared.

iii. Storey displacement and base shear:

The storey displacement and base shear of the conventional model and precast model were evaluated and compared.

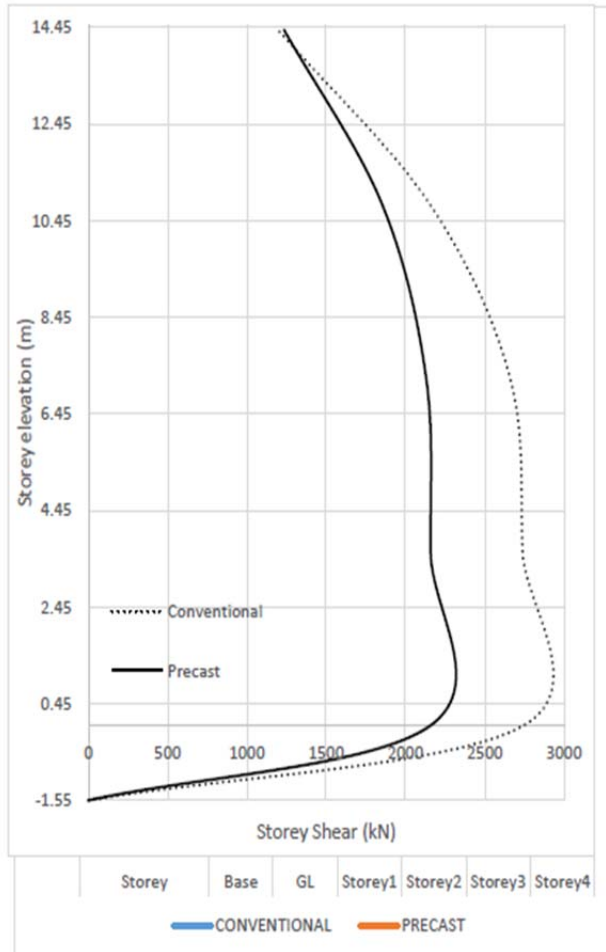
6. COMPARISON

6.1 Base shear

Base shear value is taken from ETABS and also manually calculated for both cast-in-situ and precast buildings for comparison.

BASE SHEAR FOR CONVENTIONAL MODEL(MANUAL CALCULATION VS ETABS)			
ETABS VALUES			
LOAD	FX (KN)	FY(KN)	FZ(KN)
Dead	-1.55E-06	0	16468.509
Live	-6.21E-07	0	3674.6291
wall	0	0	6790.676
eq	-2744.839	0	0
eq+y1	2.30E-05	-2744.8	0
TOTAL DEAD LOAD (KN)	23259.185	TOTAL LIVE LOAD (KN)	918.657275
Vb FROM ETABS	2744.8388		
MANUAL CALCULATION			
Z= Zone factor given in table 2	0.36		
I= Importance factor given in table 7	1		
R= Response reduction factor given in table 7	3		
h= Height of building in m	19.4		
d= Base dimension of the building at plinth level in m	22		
T	0.69		
Type of soil	II		
Sa/g	1.96		
Ah	0.1176		
Ah	0.1140		
Dead Load(KN)	23259.185		
Live Load(KN)	918.63		
W(FROM ETABS)	24177.815		
Vb	2756.2709		
DIFFERENCE IN VALUES (KN)	11.43211		

BASE SHEAR FOR PRECAST MODEL(MANUAL CALCULATION VS ETABS)			
ETABS VALUES			
LOAD	FX (KN)	FY(KN)	FZ(KN)
Dead	0	0	17953.5669
Live	0	0	3440.1372
wall	0	0	737.9951
eq	-2158.586	0	0
eq+y1	0	-2158.6	0
TOTAL DEAD LOAD (KN)	18691.562	TOTAL LIVE LOAD (KN)	860.0343
Vb FROM ETABS	2158.5859		
MANUAL CALCULATION			
Z= Zone factor given in table 2	0.36		
I= Importance factor given in table 7	1		
R= Response reduction factor given in table 7	3		
h= Height of building in m	19.4		
d= Base dimension of the building at plinth level in m	22		
T	0.69		
Type of soil	II		
Sa/g	1.96		
Ah	0.1176		
Ah	0.11		
Dead Load (KN)	18691.562		
Live Load(KN)	860.0343		
W(FROM ETABS)	19551.596		
Vb	2150.6756		
DIFFERENCE IN VALUES (KN)	-7.910307		



Considering X-direction for EQX i.e. earthquake force component in X-direction for comparison of storey shear, storey drift and storey displacement of both the cast-in-situ and precast building.

6.2 Storey shear

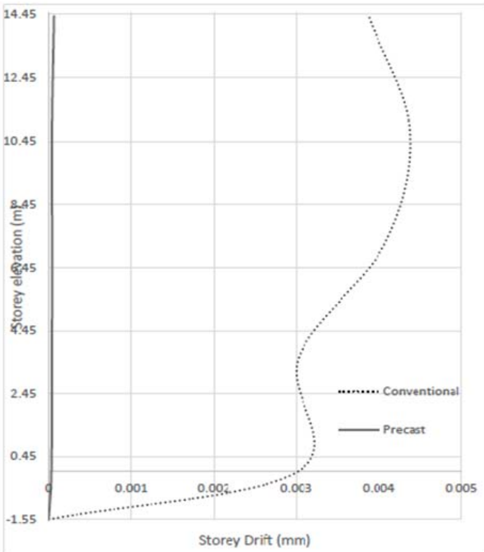
		CONVENTIONAL	PRECAST
TABLE: Storey Shear EQx			
Storey	Elevation	X-Dir	X-Dir
	m	KN	KN
Base	-1.55	0	0
GL	0	2744.8389	2158.5859
Storey1	3.6	2738.5659	2158.5859
Storey2	7.2	2659.4855	2130.2356
Storey3	10.8	2151.8318	1851.052
Storey4	14.4	1195.0814	1233.6403

Storey shear comparison

6.3 Storey Drift

		CONVENTIONAL	PRECAST
TABLE: Storey Drift Eqx			
Storey	Elevation	X-Dir	X-Dir
	m	mm	mm
Base	-1.55	0	0
GL	0	0.003035	0.000033
Storey1	3.6	0.003029	0.000039
Storey2	7.2	0.004075	0.000041
Storey3	10.8	0.004375	0.000039
Storey4	14.4	0.003877	0.000063

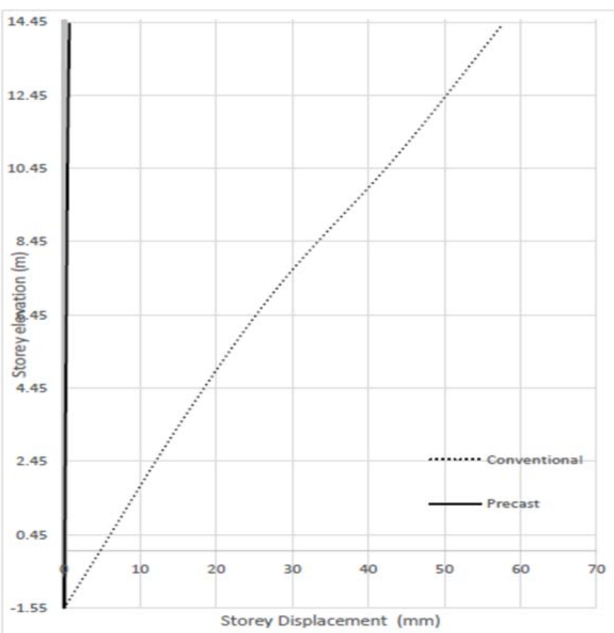
Storey drift comparison



6.4 Storey Displacement

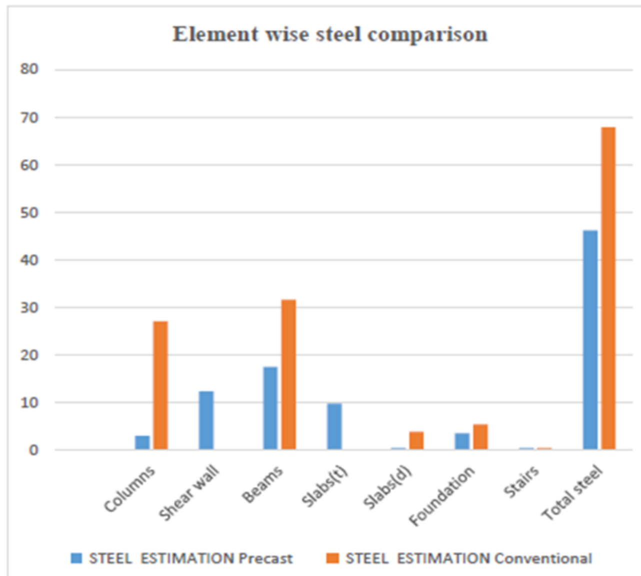
		CONVENTIONAL	PRECAST
TABLE: Storey Displacement Eqx			
Storey	Elevation	X-Dir	X-Dir
	m	mm	mm
Base	-1.55	0	0
GL	0	4.704	0.051
Storey1	3.6	15.609	0.176
Storey2	7.2	28.058	0.316
Storey3	10.8	43.758	0.451
Storey4	14.4	57.688	0.675

Storey displacement comparison



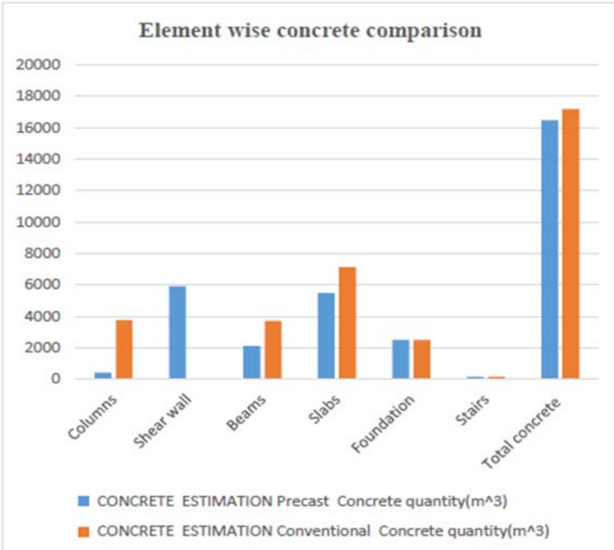
6.5 Steel comparison

STEEL ESTIMATION		
	Precast	Conventional
	Steel quantity(tonnes)	
Columns	2.8956083	26.96150702
Shear wall	12.201912	0
Beams	17.3929008	31.56214633
Slabs(t)	9.64732248	0
Slabs(d)	0.33508942	3.748733299
Foundation	3.43899793	5.327499195
Stairs	0.27366717	0.273667174
Total steel	46.1854982	67.87355302



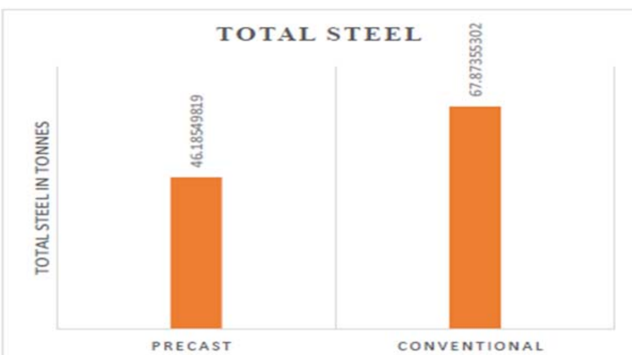
6.6 Concrete comparison

CONCRETE ESTIMATION		
	Precast	Conventional
	Concrete quantity(m^3)	
Columns	415.7772	3737.2212
Shear wall	5893.9076	0
Beams	2086.7959	3695.9559
Slabs	5470.3504	7113.0876
Foundation	2479.66	2498.119
Stairs	138.668	138.668
Total concrete	16485.1591	17183.0517



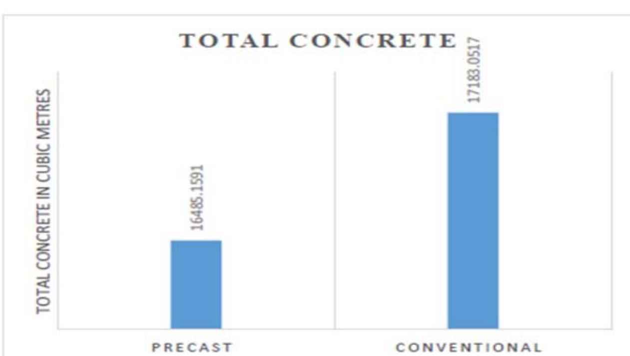
6.7 Total material comparison

Percentage difference in steel	31.9536



Steel comparison

Percentage difference in concrete	4.06152



Concrete comparison

7. RESULTS AND DISCUSSIONS

From the analysis and design, it was found that the base shear acting on the precast building was lesser than that acting on the conventional or cast-in-situ building. The base shear acting on the precast model was found out to be equal to 2158.58 KN while as that of the conventional model was found to be equal to 2744.83 KN. The reduction in base shear is a direct result of the use of shear wall in the precast model. Shear wall is a structural element used to resist horizontal forces parallel to the plane of the wall as well as gravity loads. When such a building is designed without shear walls, beams and column sizes are quite heavy, which induces heavy forces on the building member. As the base shear directly depends on the dead weight of the building, it has a higher value for the heavy cast-in-situ building as compared to the precast building.

Storey shear is the sum of design lateral forces at all levels above the storey under consideration. Base shear is the sum of the storey shear of the entire building. So as the dead weight reduces, the storey shear reduces, resulting in reduced storey shear of the precast building.

Storey drift is the drift of one level of a multi-storey building relative to the level above or below it.

Storey displacement is the drift or lateral displacement of one storey or level of the multistory building relative to the base. As storey drift and storey displacement are directly related to stiffness of the structure, so the decrease in storey drift and storey displacement of the precast building can be attributed to the increased stiffness as a result of introducing shear walls in the precast model.

The quantity of concrete required for the precast building was found to be reduced by 4.6 percent as compared to that of the cast-in-situ building. Similarly the quantity of steel was reduced by 31.9 percent in the precast building. This can be attributed to the reduced size of the structural elements in the precast building.

8. CONCLUSION

The main objective of the project was to make a comparison between cast-in-situ and precast concrete structure in terms of storey drift, storey displacement, storey shear, base shear and quantity of materials. The precast model made use of shear walls which resist the horizontal forces parallel to the plane of the wall as well as gravity loads, and also increase the stiffness of the structure. The conventional model, on the other hand, made use of heavy beams and columns which induced heavy forces on the building members. This explains the increased value of base shear in case of conventional model. The precast model showed significantly lesser values of storey shear, storey drift and storey displacement due to the increase in stiffness of the structure because of the use of shear walls. Precast concrete structure was found to be more economical in terms of quantity of materials. This was because of the size of the structural elements used.

9. ACKNOWLEDGEMENT

This work is supported by the faculty Dr. Kiran Kamath, Department of civil engineering of Manipal Institute of Technology.

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