ANALYSIS AND DESIGN OF SPIRAL STAIR OF A HIGH RISE BUILDING SUPPORTED ON A CENTRAL COLUMN

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ABSTRACT

Increased population densities due to migration of people from the countryside to the cities, combined with the rising price of developable land provide the urban planners with no better solution than to build higher. In recent decades, dwellers of Rajshahi city are constructing high rise buildings to support the current demand. Due to this increased population the demand of the number and capacities of egress routes are increased. Because of their attractive appearances and less space requirements spiral stairs become popular now-a-days. This paper involves analysis and design of a spiral stair which is supported on a central column subjected to gravity and lateral load on a 10 storied rectangular building of 93ft × 75ft size. The stair is modelled as a cantilever structure. Using the analysis results, comparative graphs are plotted among the maximum story displacements along axes (X axis and Y axis) and the permissible displacements according to BNBC 2006. It is found that the displacements are within the allowable limit. The stair is then designed and their reinforcement details are shown. It is needed to note that the central column diameter is not uniform. The diameter of spiral column is 26 inch up to story 2 and it is reduced to 20 inch in story 3 and further reduced to 16 inch in story 6 to make the design economic.

Keywords: *Spiral stair, Story displacements, Spiral column, Cantilever stairs.*

1. INTRODUCTION

The number of people especially in the cities is growing rapidly. With the increasing number of people, number of high rise building also increases simultaneously. As a result, population density in these buildings also increases. These highly populated buildings need maximum amount of exit points in the form of corridors, doors, stairways etc. In case of simple one storied building, it is very easy to evacuate the building but in case of high rise building which have floors above or below the ground, it is a very complicated case because of the vertical movement factor. Stair is the most essential element among all the exiting points in case of high rise or low rise buildings. In case of earthquake, fire accident, peak hours in a commercial building, market, office and business center, stair gives us an easy solution and makes things convenient for us. Stair can make a building more beautiful, attractive and most importantly it can make any building assembled.

Now-a-days spiral stairs are gaining popularity because of their attractive appearances and they require small amount of space. Because of their attractive appearances, they are found in many important commercial buildings besides residential buildings. Spiral column along with landing connected to main building frame provide sufficient rigidity to carry load. Therefore, extra supports are not required.

Two papers dealing with the subject has come to the attention of the author. In one paper (OVE ARUP and PARTNERS, 1959), it is confined to the particular case of simply supported column with stairs in the form of one complete turn of the spiral, and biaxial bending is not considered. In another paper, a method is proposed for the analysis of a central column supporting uniformly loaded cantilever stairs. Maximum resultant span moments obtained by means of the Newton-Raphson method are also given in tabular form (Rutenberg A., 1975). Here the purpose of this study is to analyze the stair subjected to gravity and lateral load and to design the spiral column, stair beams and stair. Comparison between the maximum story displacements along axes (X axis and Y axis) and the permissible displacements according to BNBC 2006 is also carried out.

2. METHODOLOGY

A 10 storied reinforced concrete building along with a spiral stair in its center was analyzed using ETABS 2016 software. After application of selected load patterns and load combinations according to BNBC 2006, the building was analyzed. With the analysis results, the maximum story displacements along X axis and Y axis were compared with the permissible displacements according to BNBC 2006 and the displacements were found within the allowable limit. The design of the stair was then carried out and their reinforcement details were shown. Table 1 represents the details of the building.

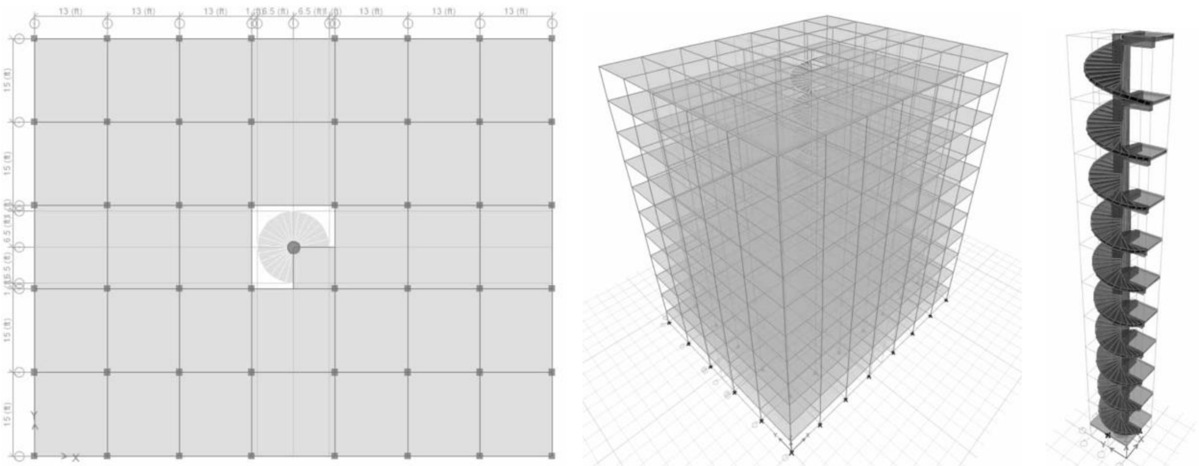
Table 1: Details of the building

Description	Parameter
Plan	93 ft × 75 ft
Story height	10 ft
Building type	Residential
Seismic zone	1
Basic wind speed	155 km/hr (Rajshahi)
Building column size	14 in × 14 in
Stair column diameter	i) Up to story 2 = 26 in ii) Up to story 5 = 20 in iii) Up to story 10 = 16 in
Beam size	i) Floor beam = 12 in × 18 in ii) Grade beam = 15 in × 21 in
Thickness of slab	5 in
Stair slab thickness	8 in
Compressive strength of concrete at 28 days	4000 lb/in^2
Maximum yield strength of rebar material	60000 lb/in^2
Minimum tensile strength of rebar material	90000 lb/in^2
Specification	BNBC 2006
Concrete Design Code	ACI 318-08

2.1 Modelling

A rectangular grid of 93ft with 7 bays along X-direction and 75ft with 5 bays along Y-direction has considered with height of about 10 stories. The stair is located at the middle of the plan. The stair is connected with the building by its landing only and there is no structural connection between the steps of the stair and the building. The stair has modelled as a cantilever structure where the central column supports the stair. The rotation angle of each flight of stair is 270°. Each flight consists of 20 steps having a turning angle of each step is 13.5°. The beams are located at the landing slab at the starting and ending of each flight. The columns of the building are rectangular while the central column of the spiral stair is circular.

Figures 1(a) and 1(b) represents the plan view and three dimensional view of 10 story building with spiral stair and Figure 1(c) represents the three dimensional view of 10 story spiral stair.



(a) (b) (c)

Figure 1: (a) Plan view of 10 story building with spiral stair, (b) Three-dimensional view of 10 story building with spiral stair, (c) Three-dimensional view of 10 story spiral stair

2.2 Load Patterns

The loads to be applied on the building are shown in Table 2.

Table 2: Selected load patterns

Load	Type	Applied load
Dead Load	Dead	Self-weight of stair
Building Live Load	Live	50 psf (BNBC 2006)
Stair Distributed Load	Live	100 psf (BNBC 2006)
Stair Concentrated Load	Live	1.05 k (BNBC 2006)
Handrail Load	Superimposed Dead	0.03 k (BNBC 2006)
Floor Finish	Superimposed Dead	30 psf (BNBC 2006)
Partition Wall Load	Superimposed Dead	30 psf (BNBC 2006)
Earthquake X	Seismic	According to BNBC 2006
Earthquake Y	Seismic	According to BNBC 2006
Wind Load X	Wind	According to BNBC 2006
Wind Load Y	Wind	According to BNBC 2006

2.3 Spiral Column Dimension

From the design, it has found that the spiral column diameter of 26 inch is adequate from GF to story 2 and 20 inch is adequate from story 3 to story 5. Again, the spiral column diameter of 16 inch is adequate from story 6 to story 10. So, the diameter of the spiral column is reduced to 20 inch in story 3 and further reduced to 16 inch in story 6 to make the design economic. As the total dimension of the staircase is uniform and the column diameter is not same throughout the total height of the building, so the width of the trade is not uniform, it varies with the distance from column face to the free end. The following are some of the modelling information of stair provided in Table 3.

Table 3**:** Modelling information of stair

Story	Column diameter in	Width of stair	Width of trade at column face in	Width of trade at free end in
Story 10	16	5'-10"	1.90	18.34
Story 9	16	5'-10"	1.90	18.34
Story 8	16	5'-10"	1.90	18.34
Story 7	16	5'-10"	1.90	18.34
Story 6	16	5'-10"	1.90	18.34
Story 5	20	5'-8"	2.40	18.34
Story 4	20	5'-8"	2.40	18.34
Story 3	20	5'-8"	2.40	18.34
Story 2	26	5'-5"	3.10	18.34
Story 1	26	5'-5"	3.10	18.34

3. ANALYSIS AND DESIGN

3.1 Analysis Results and Comparison

From the analytical analysis of the model the result of various parameters like lateral story displacement, story drift etc. are observed and the comparative study of maximum story displacement with respect to permissible story displacement according to BNBC 2006 has done. Story wise maximum displacements are shown in Table 4.

Table 4: Story wise maximum displacements

Story	**Maximum story displacement according to BNBC 2006 in**	**Story displacement along X axis in**	**Story displacement along Y axis in**
Story 10	4.80	1.156985	1.289929
Story 9	4.32	1.117233	1.270331
Story 8	3.84	1.055994	1.228851
Story 7	3.36	0.975456	1.163728
Story 6	2.88	0.878018	1.075609
Story 5	2.40	0.766038	0.964894
Story 4	1.92	0.642355	0.834220
Story 3	1.44	0.509508	0.682412
Story 2	0.96	0.369939	0.510522
Story 1	0.48	0.228098	0.324074

The maximum story displacement along X axis and Y axis occurred in the model are compared with the permissible maximum story displacement according to BNBC 2006 in Figures 2 and 3 respectively.

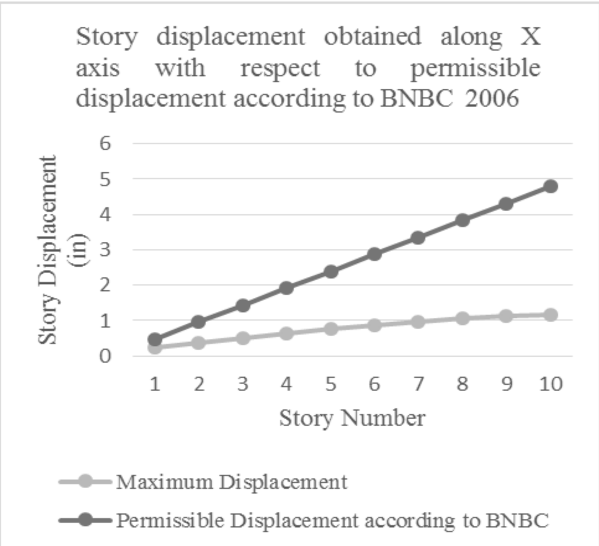


Figure 2: Story displacement along X axis

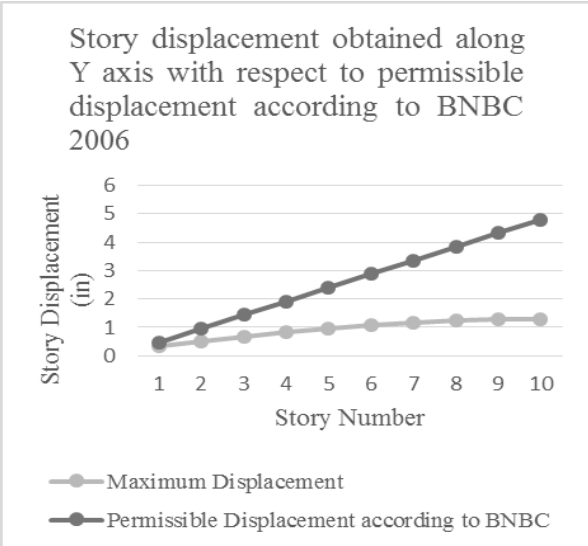


Figure 3: Story displacement along Y axis

From Figures 2 and 3, it is observed that the maximum story displacement along X axis and Y axis are less than the permissible value obtained from BNBC 2006. Also, story displacement along X axis and Y axis increases almost linearly with the increase of story height up to 10th story.

3.2 Design Considerations and Reinforcement Details

The design of spiral stair along with the beams and central column and their reinforcement details are as follows.

3.2.1 Design of Beam

The identification of beam is represented by the following Figure 4:

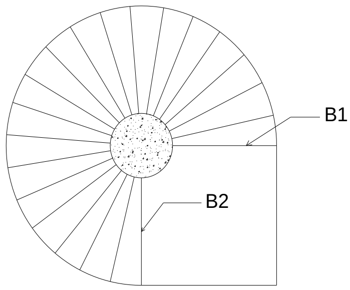


Figure 4: Identification of beam

The beam schedule is shown in Table 5 and typical reinforcement details of beams are shown in Figures 5 and 6.

Table 5: Concrete beam schedule

Beam ID	Story	Span length H	Section size			Longitudinal bars		Stirrup	Typical section
			Width in	Depth in	Effective depth in	Top bars A	Bottom bars B		
B1	Story 10	6'-10"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B2	Story 10	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B1	Story 9	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B2	Story 9	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B1	Story 8	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B2	Story 8	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B1	Story 7	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B2	Story 7	6'-10"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 6	6'-10"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B2	Story 6	6'-10"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 5	6'-8"	12	18	15.5	3#5	4#5	#3@6" c/c	2S
B2	Story 5	6'-8"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 4	6'-8"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B2	Story 4	6'-8"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 3	6'-8"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B2	Story 3	6'-8"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 2	6'-5"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B2	Story 2	6'-5"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	Story 1	6'-5"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B2	Story 1	6'-5"	12	18	15.5	3#5	3#5	#3@6" c/c	1S
B1	GF	6'-5"	15	21	18.5	4#5	4#5	#3@4" c/c	3S
B2	GF	6'-5"	15	21	18.5	4#5	4#5	#3@4" c/c	3S

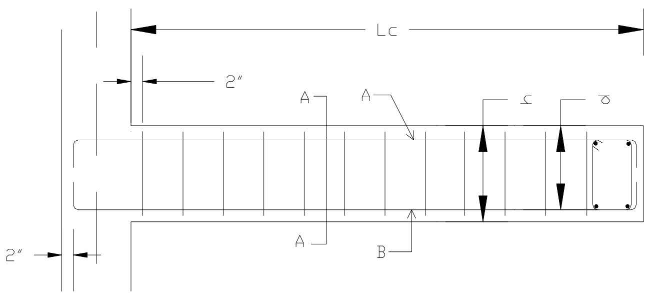


Figure 5: Typical concrete beam elevation

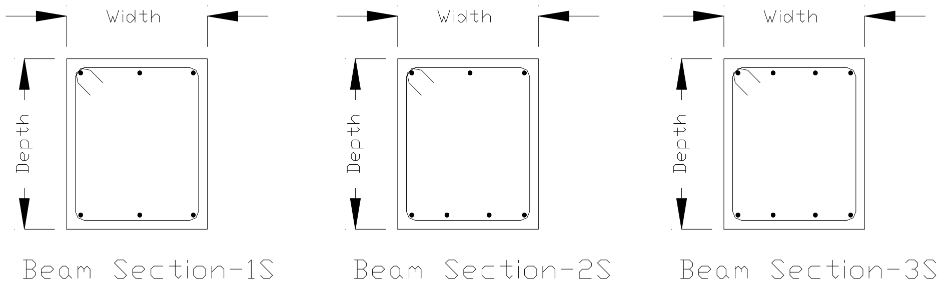


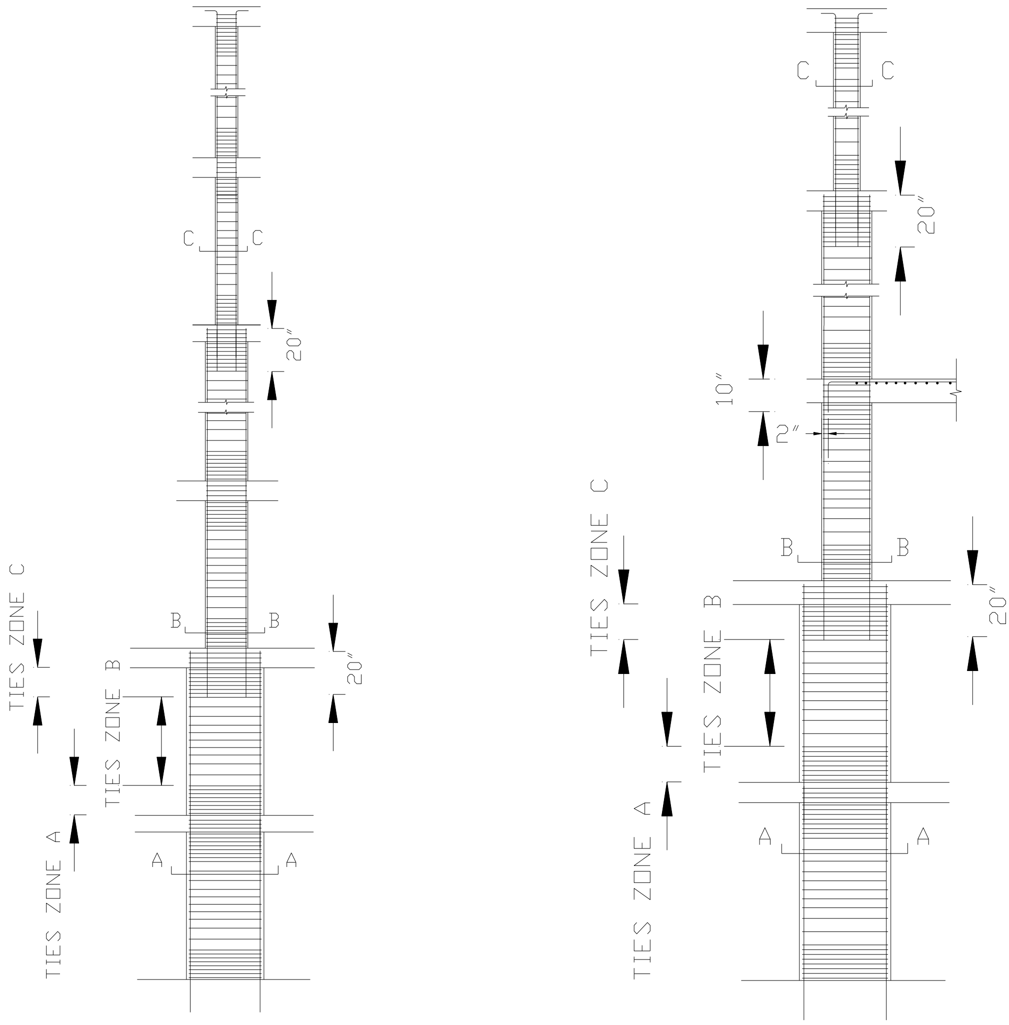
Figure 6: Typical concrete beam sections

3.2.2 Design of Spiral Column

The central column supports the stair and the beams. The column in each story is divided into three ties zone. Table 6 represents the column schedule and typical reinforcement details of column are shown in Figures 7(a) and 8(a). Reinforcement details of column and stair is shown in Figure 7(b). Figure 8(b) represents magnified view of lapping of column reinforcement.

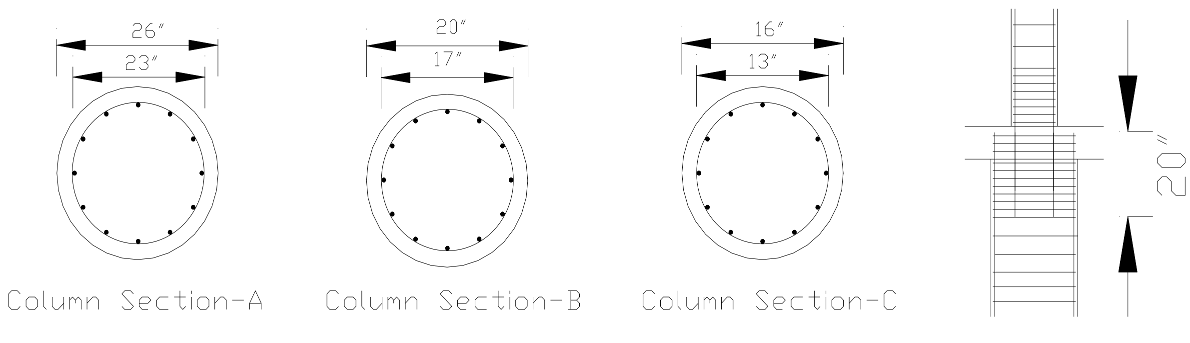
Table 6: Concrete column schedule

Story	Length of ties zone A ft	Length of ties zone B ft	Length of ties zone C ft	Section	Reinforce-ment	Ties zone A	Ties zone B	Ties zone C
Story 10 Story 9 Story 8 Story 7 Story 6	1'-8"	6'-8"	1'-8"	C-C	12#5 bar	#3@4" c/c	#3@6" c/c	#3@4" c/c
Story 5 Story 4 Story 3	1'-8"	6'-8"	1'-8"	B-B	12#5 bar			
Story 2 Story 1 GF	2'-2"	5'-8"	2'-2"	A-A	12#6 bar			



(a) (b)

Figure 7: (a) Reinforcement details of central column, (b) Reinforcement details of column with stair connection



(a) (b)

Figure 8: (a) Reinforcement details of column sections, (b) Magnified view of lapping of column reinforcement

3.2.3 Design of Stair

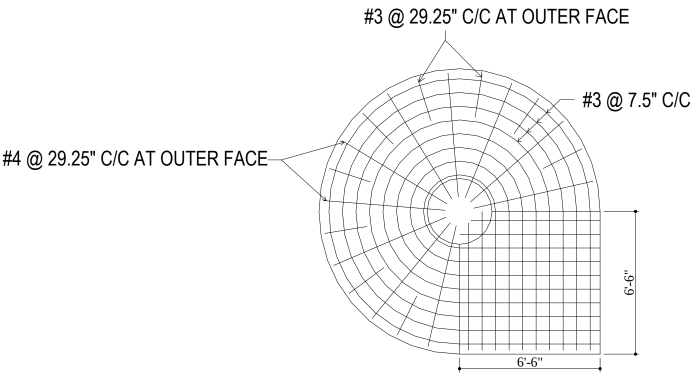
In the design of stair, #4 bar is used as main reinforcement. The spacing of main reinforcement at various sections of stair are shown in Table 7 as follows.

Table 7: Spacing of main reinforcement (#4 bar)

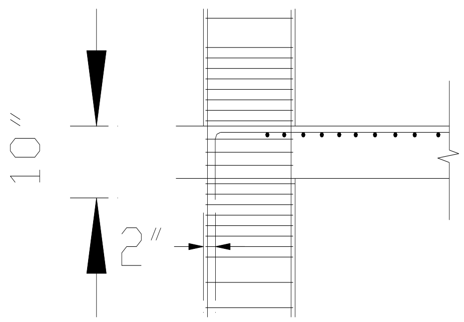
Story		Location	Spacing
From	**To**		**in**
Story 6	Story 10	Column face	3
		Mid span	14.625
		Outer face	29.25
Story 3	Story 5	Column face	3.75
		Mid span	18.25
		Outer face	29.25
Story 1	Story 2	Column face	4.875
		Mid span	23.75
		Outer face	29.25
Note: 1. Outer face is located 2" from the edge of free end of stair.			

But according to ACI code, spacing should not be more than 18". Therefore alternative #3 bars are placed in between #4 bars. #3 bar is located in between #4 bar from free end to a distance of 2' towards the center of column.

#3 bar is used as distribution reinforcement @ 7.5" c/c. These reinforcements are continuous at the edge of landing slab. The details of stair reinforcement at section C-C is shown in Figure 9(a) and Figure 9(b) represents the magnified view of reinforcement details of column and stair connection. Figures 10 and 11 represent reinforcement details of stair at outer face and column face respectively.



(a)



(b)

Figure 9: (a) Reinforcement details of stair at section C-C, (b) Magnified view of reinforcement details of column and stair.

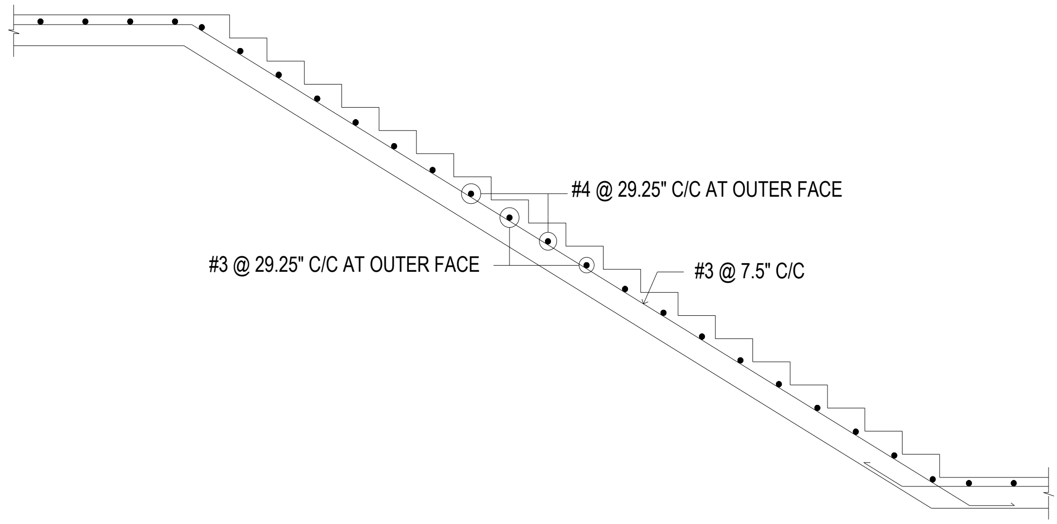


Figure 10: Reinforcement details of stair at outer face

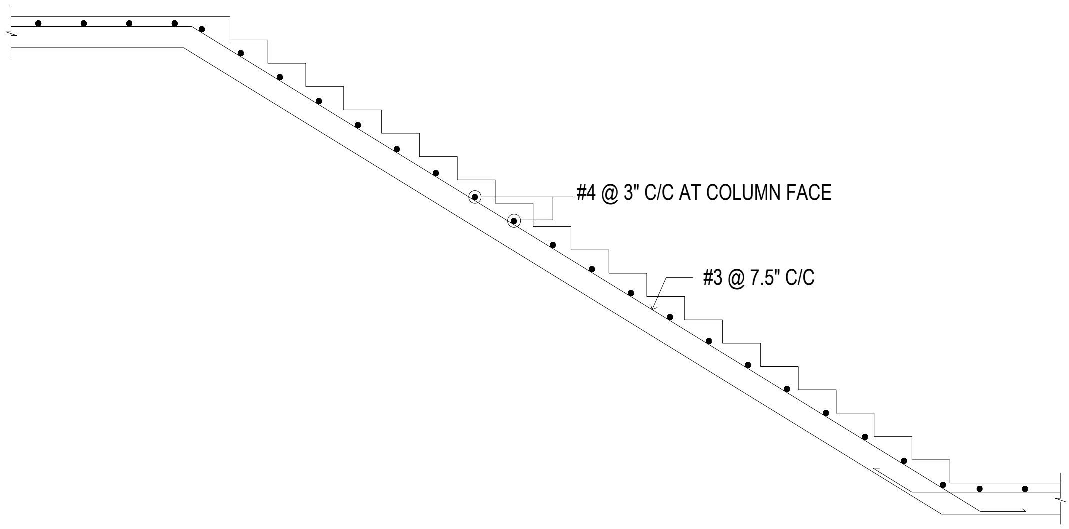


Figure 11: Reinforcement details of stair at column face

4. CONCLUSIONS

a. The maximum story displacement along X axis and Y axis occurred in the spiral stair model are compared with the permissible maximum story displacement according to BNBC 2006. The maximum story displacement along X axis and Y axis are less than the permissible value obtained from BNBC 2006.

b. Story displacement along X axis and Y axis increases almost linearly.

c. In economic point of view, the diameter of the spiral column is not uniform. The column diameter of 26 inch is adequate for all the story. But the diameter of 26 inch is not required above story 2 and diameter of 20 inch is required above story 2. However, diameter of 20 inch is not required above story 5. So, the diameter of the spiral column is reduced to 20 inch in story 3 and further reduced to 16 inch in story 6 to make the design economic.

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