Assessment of Strengthening Scheme of Existing Buildings Extended by Adding Additional Floors

Bayan S. Al-Nu'man[1]

[1] Civil Engineering Department, Faculty of Engineering, Ishik University, Erbil, Iraq
Correspondence: Bayan Al-Nu'man, Ishik University, Erbil, Iraq.
Email: bayan.salim@ishik.edu.iq

Received: September 15, 2016 Accepted: November 4, 2016 Online Published: December 1, 2016

doi: 10.23918/eajse.2414214

Abstract: This study intends to analyze and design existing RC frames, of different concrete compressive strengths when extended by adding more floors to the existing buildings. It may be decided whether a strengthening scheme is feasible or not.

In this work, analyses are made of 3 buildings of 14-stories with different compressive strengths in the first 6-floor columns for each building, extended to 16-stories frame by adding 2 stories of Normal weight concrete (NWC) or Steel.

A case study is selected which is an existing RC buildings, and the owner requested 2 additional floors. It is assumed that the foundation system is capable of carrying the additional floors. First the capacity of the superstructures must be known, by using data obtained from the previous designs of the existing buildings.

After extending the building by NWC or Steel, by using STAAD-pro, it has been shown that a considerable portion of the total number of columns in the superstructure of the existing building couldn't carry the new loads due to the additional 2 floors, so in order to add two additional floors, strengthening scheme must be planned for the columns which require additional capacity.

Keywords: Existing Building, Additional Floor, Strengthen

1. Introduction

The extension of (adding stories to) existing buildings is required in development of urban construction all over the world. With the increase of population, cities are bound to expand but actual area of individual city is limited. It is therefore necessary to confine the development within the scope of the city properly. This requires raising the height of buildings in the city, especially where existing buildings are very low in height.

There are some solutions to this issue:

1. Demolishing the existing building and construct new high rise building at the site. But it will cause problem of moving people to other place, cost of demolishing, and the disposal of waste from the construction site despite of these problems there are some buildings are demolished without reaching their service life.

2. Raising the height of the existing buildings. This comprises mainly in the following process:
   a. The existing building has capacity to carry the extension of building, which means the

weight additional floors are to be supported by the existing building structure. However the capacity of the existing building is limited, only one or two floors can be added at most.

b. If the foundation could carry the extension but the super structure couldn't then one of these strengthening methods shall be planned to increase the capacity of super structure.
c. The extension is done by means of pure frame: the weight of additional floors can't be transmitted by the super-structure to the foundation, because the existing structure has not taken into consideration that the building will be extended.
d. Anchoring the new additional frame to the existing frame should be securely executed (Slao, 1994).

2. Objective

The objectives of this study are to generate structural design and techniques to be used when adding more floors on existing buildings without demolishing the existing buildings by using a case study of residential reinforced concrete buildings. Different concrete compressive strengths are used to study their effects. Furthermore, this research also intends to develop possibility of using lightweight materials (Steel), as a solution for additional stories on existing buildings.

3. Analyses of the Case Study

The case study consists of 3 residential reinforced concrete buildings of 14 floors. In the first building the overall compressive strength of 28 MPa is used, in the second and third buildings the first 6 floor columns are of high strength concrete (ACI, 2010); 56 MPa and of 84MPa compressive strength, respectively, with the remaining columns of 28 MPa.

The owner wants to add two more floors; 16-floor building rather than 14-.

There are two solutions of providing these additional floors to the existing buildings; first one is demolishing the existing building and constructing a new one, and the second is adding floors on the existing buildings.

The second option will be selected.

The major problem is to know if the old buildings can support the new one or look for other structural solutions.

It is assumed that the foundations are fixed and can support the extension loading safely, then only the super structure behavior of the existing buildings is a key factor to know whether the new and the old structures can be integrated or not. Surely, the existing roof floor systems are now an intermediate floor in the extended building. When two floors are added, a live load of 5 kN/m^2 is used for these floors, so any measure of strengthening if required for the slab is assumed taken.

Steel or Normal Weight Concrete is used in the extension part of the existing buildings.

In the beginning of the work, the area of steel for each member of the existing buildings will be taken from the previously designed plans.

Due to adding two floors to the existing building, strengthening schemes of the existing super structures are required.

4. Structural Information about the Case Study

All beams and columns dimensions are given below:

-Beam section dimension 400 mm wide by 600 mm deep.
-Interior Column section dimension from 1st up to 6th floor is 800 mm by 800 mm, from 7th up to 11th floor is 600 mm by 600 mm, and from 12th up to 14th+15thand 16thfloor is 400 mm by400 mm.
-Exterior Column dimensions from 1st up to 11th floor is 600 mm by 600 mm, and from 12th up to 14th+15thand 16th floor is 400*400 mm

Thickness of the slab is 200 mm
Thickness of slab for composite floor system = 100mm
Height of each story 3 m, except for ground floor the height is 4 m
Concrete strengths are f'_c= 28 , 56, and 84 MPa.
Steel yield strength f_y = 420 MPa
Density of concrete= 24 kN/m^3
Density of light weight concrete (used for the floor system of Steel) = 18 kN/m^3
Minimum concrete cover for the reinforcement for beams and columns = 40 mm

Steel sections yield strength, f_y = 345 MPa, and maximum tensile strength f_u = 450 MPa

In this work, theoretical investigation of the moment, shear, and axial forces are conducted by using computer program (STAAD Pro 2007 V8i). A typical floor of the studied building consists of 4 bays of spans 7 m, 5.2 m, 5.2 m and 7 m center-to-center in each direction. Design of sections follows ACI 318 – 14 code (ACI, 2014).

5. Results

Results of required reinforcement ratio (%), before adding the new floors, are listed in tables (1) and (2), and figures (1) and (2), for selected interior and edge columns, respectively, in each floor corresponding to different concrete strengths. Note the ground floor columns' greater requirement and at the 6th floor when column sizes are reduced. A minimum ratio is 1% according to ACI code. [(4)] However, when strength is increased to 56 or 84 MPa, only the minimum reinforcement ratio is required in the ground floor columns.

Tables (3) to (8) and figures (3) to (8) show the variation of steel requirements after extension of two additional floors, corresponding to variations in concrete strengths from 28 to 56 to 84 MPa, for typical interior and edge columns.

9 out of 14 (9 / 14) interior columns require strengthening using 28 MPa, corresponding to (5 / 14) using 56 MPa, and 84 MPa concrete strength. The respective numbers are (8/14), (3/14) for edge columns.

Table 1: Reinforcement percentage with different concrete strengths f'_c before extension, for selected interior columns

Interior columns			Fc'		
			28	56	84
floor(s)	Col. No.	Dim(mm)	As%		
Ground	83	800*800	3.37	1	1
1st	176	800*800	2.76	1	1
2nd	269	800*800	1	1	1
3rd	362	800*800	1	1	1
4th	455	800*800	1	1	1
5th	548	800*800	1	1	1
6th	641	600*600	3.27	3.27	3.27
7th	734	600*600	1	1	1
8th	827	600*600	1	1	1
9th	920	600*600	1	1	1
10th	1013	600*600	1	1	1
11th	1106	400*400	1	1	1
12th	1199	400*400	1	1	1
13th	1292	400*400	1	1	1

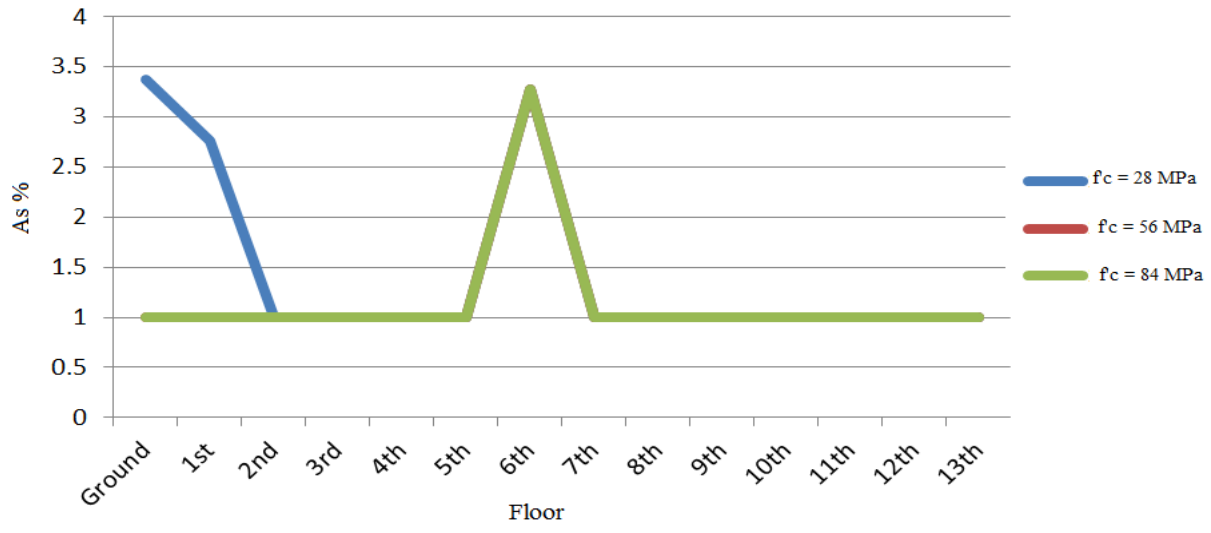

Figure 1: Effect of concrete strength on steel ratio for a typical interior columns before extension

Table 2: Reinforcement percentage with different concrete strengths f'_c before extension, for typical edge columns

Edge columns			Fc'		
			28	56	84
floor(s)	Col. No.	Dim(mm)	As%		
Ground	90	600*600	4.18	1	1
1st	183	600*600	3.57	1	1
2nd	276	600*600	2.68	1	1
3rd	369	600*600	1	1	1
4th	462	600*600	1	1	1
5th	555	600*600	1	1	1
6th	648	600*600	1	1	1
7th	741	600*600	1	1	1
8th	834	600*600	1	1	1
9th	927	600*600	1	1	1
10th	1020	600*600	1	1	1
11th	1113	400*400	1	1	1
12th	1206	400*400	1	1	1
13th	1299	400*400	1.69	1.69	1.69

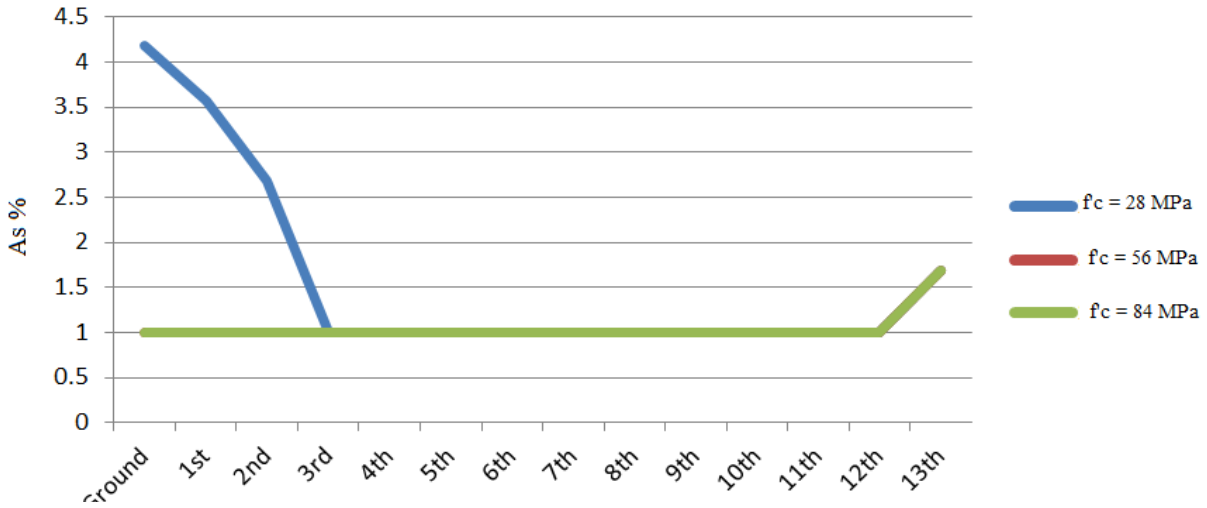

Figure 2: Effect of concrete strength on steel ratio for a typical edge columns before extension

Table 3: Reinforcement percentage variation before and after extension and strengthening requirement for typical interior columns, for concrete strength f'_c = 28 MPa

Typical Interior columns				F'c=28	MPa	
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	83	800*800	3.37	4.71	4.71	Required
1st	176	800*800	2.76	3.92	3.68	Required
2nd	269	800*800	1	3.14	3.01	Required
3rd	362	800*800	1	2.45	2.16	Required
4th	455	800*800	1	1	1	Not required
5th	548	800*800	1	1	1	Not required
6th	641	600*600	3.27	5.36	5.36	Required
7th	734	600*600	1	4.18	3.81	Required
8th	827	600*600	1	3.27	2.68	Required
9th	920	600*600	1	1	1	Not required
10th	1013	600*600	1	1	1	Not required
11th	1106	400*400	1	6.03	6.03	Required
12th	1199	400*400	1	3.68	3.14	Required
13th	1292	400*400	1	1	1	Not required
14th	1385	400*400	-	1	-	-
15th	1478	400*400	-	1	-	-

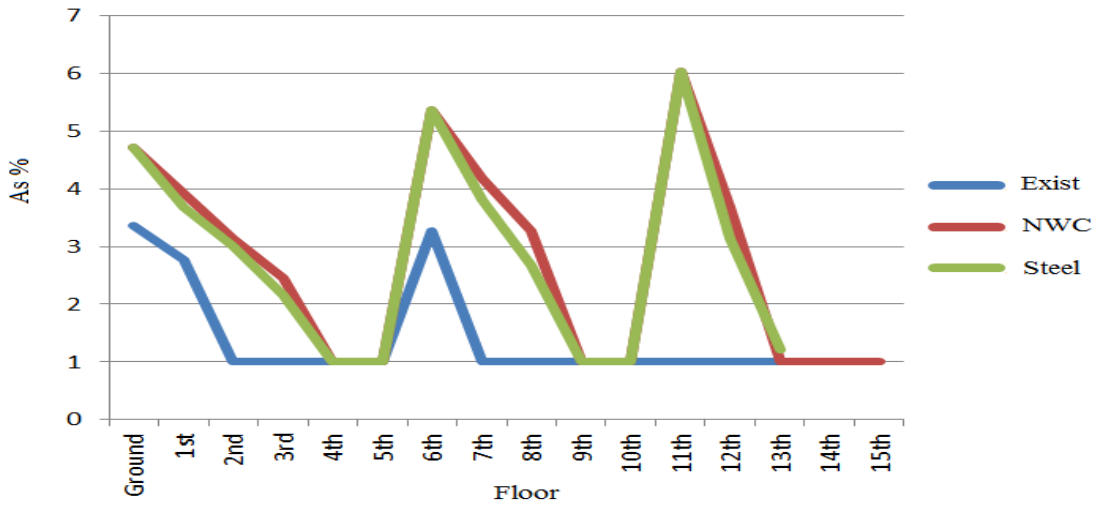

Figure 3: Variation of steel ratio after extension for interior columns, for f'c =28MPa

Table 4: Reinforcement percentage variation before and after extension and strengthening requirement for typical interior columns, for concrete strength f'_c = 56 MPa

Typical Interior columns			F'c=56 MPa			
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	83	800*800	1	1.22	1	Required
1st	176	800*800	1	1	1	Not required
2nd	269	800*800	1	1	1	Not required
3rd	362	800*800	1	1	1	Not required
4th	455	800*800	1	1	1	Not required
5th	548	800*800	1	1	1	Not required
6th	641	600*600	3.27	5.36	5.36	Required
7th	734	600*600	1	4.18	3.81	Required
8th	827	600*600	1	3.27	2.68	Required
9th	920	600*600	1	1	1	Not required
10th	1013	600*600	1	1	1	Not required
11th	1106	400*400	1	6.03	6.03	Required
12th	1199	400*400	1	3.68	3.14	Required
13th	1292	400*400	1	1	1	Not required
14th	1385	400*400	-	1	-	-
15th	1478	400*400	-	1	-	-

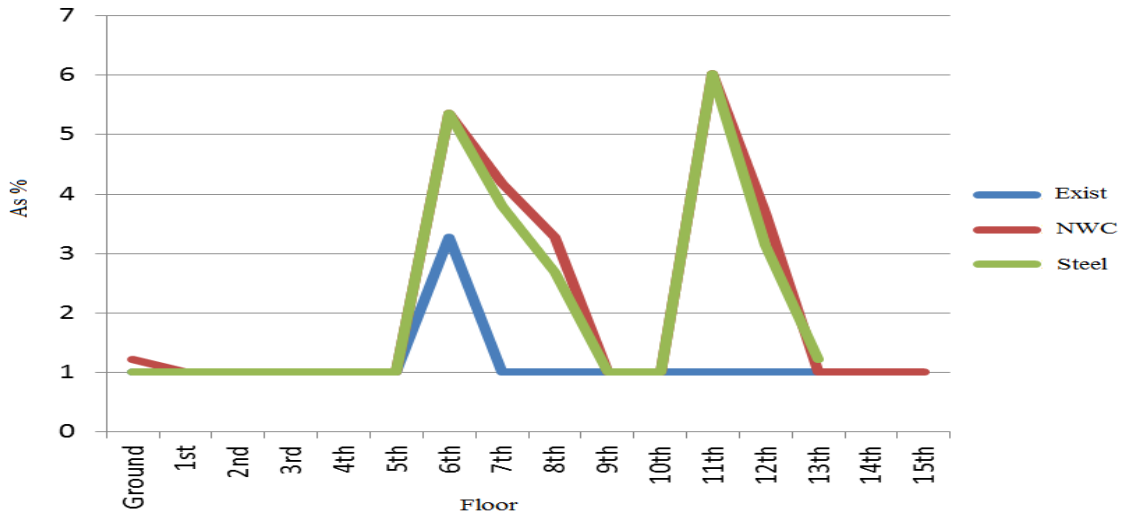

Figure 4: Variation of steel ratio after extension for interior columns, for f'_c =56MPa

Table 5: Reinforcement percentage variation before and after extension and strengthening requirement for typical interior columns, for concrete strength f'_c = 84 MPa

Typical Interior columns			F'c=84 MPa			
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	83	800*800	1	1	1	Not required
1st	176	800*800	1	1	1	Not required
2nd	269	800*800	1	1	1	Not required
3rd	362	800*800	1	1	1	Not required
4th	455	800*800	1	1	1	Not required
5th	548	800*800	1	1	1	Not required
6th	641	600*600	3.27	5.36	5.36	Required
7th	734	600*600	1	4.18	3.81	Required
8th	827	600*600	1	3.27	2.68	Required
9th	920	600*600	1	1	1	Not required
10th	1013	600*600	1	1	1	Not required
11th	1106	400*400	1	6.03	6.03	Required
12th	1199	400*400	1	3.68	3.14	Required
13th	1292	400*400	1	1	1	Not required
14th	1385	400*400	-	1	-	-
15th	1478	400*400	-	1	-	-

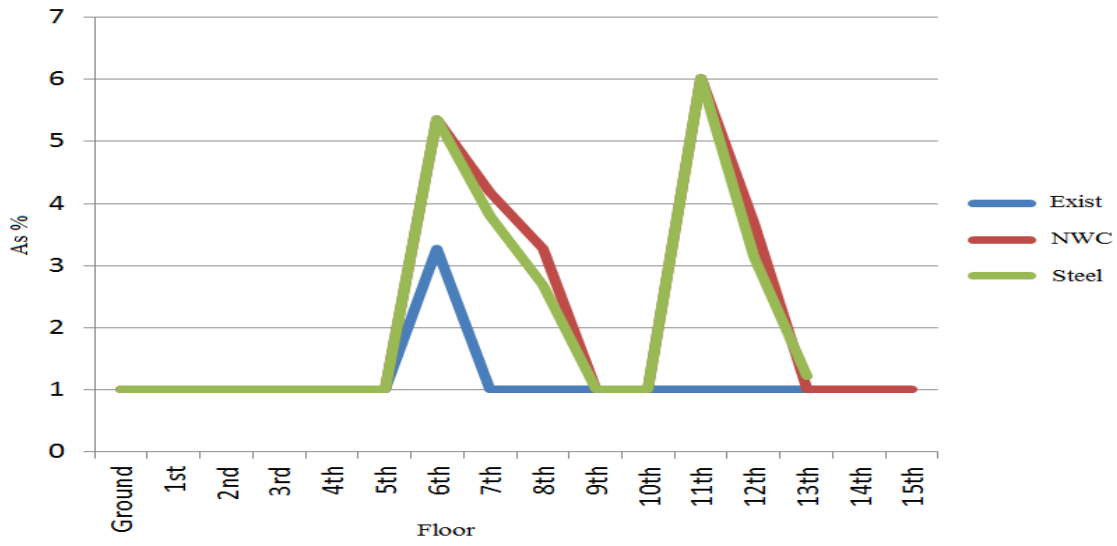

Figure 5: Variation of steel ratio after extension for interior columns, for f'c =84MPa

Table 6: Reinforcement percentage variation before and after extension and strengthening requirement for typical edge columns, for concrete strength f'_c = 28 MPa

Typical Edge columns			F'c=28MPa			
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	90	600*600	4.18	6.54	5.36	Required
1st	183	600*600	3.57	5.36	4.46	Required
2nd	276	600*600	2.68	4.18	3.81	Required
3rd	369	600*600	1	3.57	3.27	Required
4th	462	600*600	1	2.68	2.18	Required
5th	555	600*600	1	1	1	Not required
6th	648	600*600	1	1	1	Not required
7th	741	600*600	1	1	1	Not required
8th	834	600*600	1	1	1	Not required
9th	927	600*600	1	1	1	Not required
10th	1020	600*600	1	1	1	Not required
11th	1113	400*400	1	3.14	2.01	Required
12th	1206	400*400	1	2.01	1.57	Required
13th	1299	400*400	1.69	1.22	3.14 [1]	Required
14th	1392	400*400	-	1.22	-	-
15th	1485	400*400	-	2.35	-	-

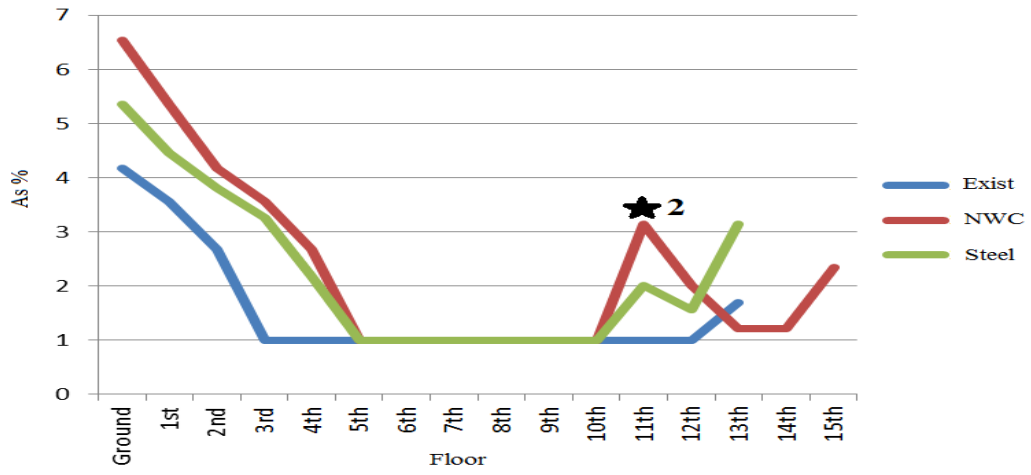

Figure 6: Variation of steel ratio after extension for edge columns, for f'c =28MPa

(1) In the 14th floor, all the moments are transferred to the column below, that's why the percentage of two additional floors is more than the NWC.
(*2) Reduction of the cross section size is made at 11th floor, so sudden change of reinforcement is occurred.
Same notes are valid for figures (7) and (8).

Table 7: Reinforcement percentage variation before and after extension and strengthening requirement for typical edge columns, for concrete strength f'_c = 56 MPa

Typical Edge columns			F'c = 56 MPa			
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	90	600*600	1	1.25	1	Required
1st	183	600*600	1	1.63	1	Required
2nd	276	600*600	1	1	1	Not required
3rd	369	600*600	1	1	1	Not required
4th	462	600*600	1	1	1	Not required
5th	555	600*600	1	1	1	Not required
6th	648	600*600	1	1	1	Not required
7th	741	600*600	1	1	1	Not required
8th	834	600*600	1	1	1	Not required
9th	927	600*600	1	1	1	Not required
10th	1020	600*600	1	1	1	Not required
11th	1113	400*400	1	3.14	2.01	Required
12th	1206	400*400	1	2.01	1.57	Required
13th	1299	400*400	1.69	1.22	3.14 [1]	Required
14th	1392	400*400	-	1.22	-	-
15th	1485	400*400	-	2.35	-	-

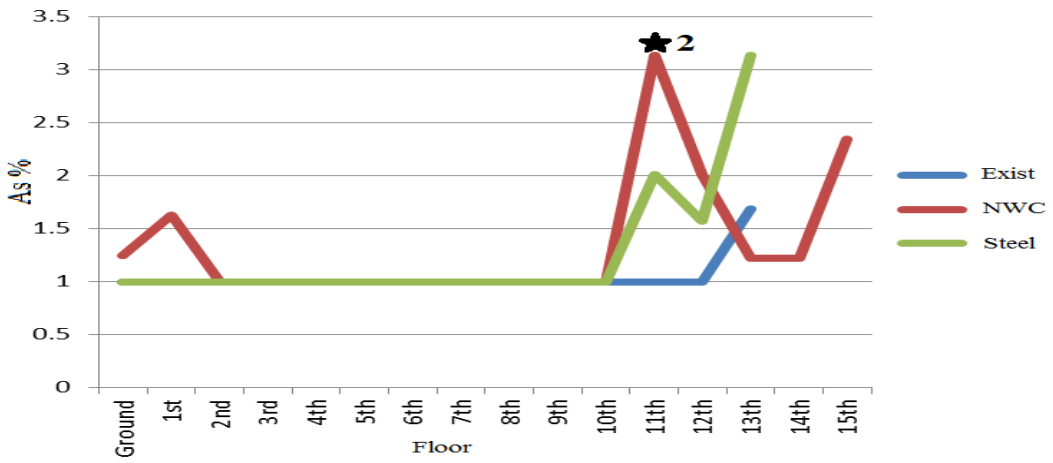

Figure 7: Variation of steel ratio after extension for edge columns, for f'c =56MPa

Table 8: Reinforcement percentage variation before and after extension and strengthening requirement for typical edge columns, for concrete strength f'_c = 84 MPa

Typical Edge columns			F'c = 84 MPa			
floor(s)	Col. No.	Dim(mm)	Existing building	Extension with NWC	Extension with Steel	Strengthening
Ground	90	600*600	1	1	1	Not required
1st	183	600*600	1	1	1	Not required
2nd	276	600*600	1	1	1	Not required
3rd	369	600*600	1	1	1	Not required
4th	462	600*600	1	1	1	Not required
5th	555	600*600	1	1	1	Not required
6th	648	600*600	1	1	1	Not required
7th	741	600*600	1	1	1	Not required
8th	834	600*600	1	1	1	Not required
9th	927	600*600	1	1	1	Not required
10th	1020	600*600	1	1	1	Not required
11th	1113	400*400	1	3.14	2.01	Required
12th	1206	400*400	1	2.01	1.57	Required
13th	1299	400*400	1.69	1.22	3.14[1]	Required
14th	1392	400*400	-	1.22	-	-
15th	1485	400*400	-	2.35	-	-

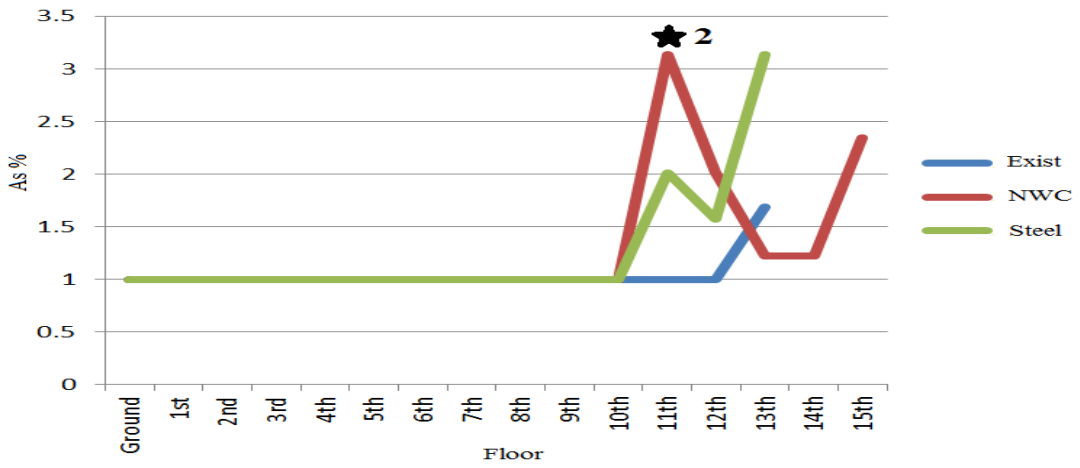

Figure 8: Variation of steel ratio after extension for edge columns, for f'c =84MPa

6. Discussions and conclusions

6.1 Effect of Varying Concrete Compressive Strength on Reinforcement Ratio of Columns of Existing Building before Extension

1. When strength f'_c = 56 MPa is used for the first six floor columns, all the percentage of columns were changed, except the columns which minimum reinforcement were used, however, there weren't any significance change between (84 and 56) MPa in the reinforcement percentage, since most of the columns were designed according to the minimum reinforcement in columns (1%), so it is better to use smaller cross sections in columns when high strength concrete is used
2. There weren't any change for the columns from 6th floor to 13th floor since they have the same f'_c of 28 MPa.

6.2 Investigation of Existing Buildings after Extension

1. Strengthening scheme of existing buildings are required, since some of the columns couldn't carry the additional load of the extensions for the studied existing buildings of 14-floors when 2 additional floors of Steel or NWC added to the old buildings. Normally wind loads were taken into account and it didn't change the results significantly after extensions.
2. When NWC is used for the extension of existing building with column f'_c = 28 MPa, the percentage of existing columns need to be strengthened is (146/490=29.8%). When Steel is used for the extension, the percentage is (141/490= 28.7%).
3. When NWC is used for the extension of existing building with column f'_c = 56 MPa, the percentage of existing columns need to be strengthened is (85/490 = 17.3%). When Steel is used for the extension, the percentage is (81/490 = 16.5%).
4. When NWC is used for the extension of existing building with column f'_c = 84 MPa, the percentage of existing columns need to be strengthened is (69/490 = 14%). When Steel is used for the extension, the same percentage is obtained (69/490 = 14%).
5. However, for Steel, the strengthening scheme is less intensive than that for the NWC, since the additional strength required is much less. In some cases, the same percentage is found for both NWC and Steel. This is because what is shown is the provided percentage. In fact, the analytical required is less, but it is rounded up for the practical reasons. The higher value of f'_c was used, the less number of columns needed to be strengthened.
6. Interior columns are more affected by the extension than the edge columns, for example for existing building with f'_c= 28 MPa; the percentage of interior columns need to be strengthened is 16.9% while for edge columns are 11.83% when Steel is used. For NWC the percentage of interior columns need to be strengthened is 17.95% while for edge columns are 11.83%.
7. The greatest critical difference detected was in edge column (no. 183), approximately 6.03% of reinforcement required for existing column with 1.69% of steel percentage, therefore special strengthening scheme is recommended.
8. As expected, the upper floor corner columns of existing building had shown improvement in strength after extension by NWC. The additional compression (larger axial load) will reduce the tensile stress in steel in the tension zone (Nilson, 2012; Wright & MacGregor 2012).

References

Siao, W.B. (1994). Reinforced Concrete Column Strength at Beam/Slab and Column Intersection. *ACI Str. Journal*, 91(1), 3-9.

ACI Committee 363. (2010). 363R -10 Report on High Strength Concrete, ACI 363 R-10, Detroit: American Concrete Institute.

Technical reference manual STAAD Pro 2007 V8i, Bentley system, 572p.

ACI Committee 318. (2014). Building Code Requirements for Reinforced Concrete, ACI 318-14, Detroit: American Concrete Institute.

Nilson AH, Darwin D, Dolan CW. (2010). *Design of Concrete Structures* (Fourteenth Edition). New York: The McGraw Hill Companies.

Wight, J. K., & MacGregor, J. (2012). *Reinforced Concrete, Mechanics and Design* (6th Edition). New York: Pearson.