IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 1 Ser. V (Jan. - Feb. 2019), PP 22-35
www.iosrjournals.org

Interactive Implementation of Axial Stiffness Reduction Factors in Thermal Analysis of Multistory Buildings

Hisham A. El-Arabaty[1], Gamal H. Mahmoud[2], Nasr E. Nasr[3], Mohamed A. Abdul Rahim[4]

[1] *(Structural Engineering Department, Faculty of Engineering/ Ain-Shams University, Cairo, Egypt)*
[2] *(Structural Engineering Department, Faculty of Engineering/ Ain-Shams University, Cairo, Egypt)*
[3] *(Structural Engineering Department, Faculty of Engineering/ Ain-Shams University, Cairo, Egypt)*
[4] *(Structural Engineering Department, Faculty of Engineering/ Ain-Shams University, Cairo, Egypt)*
Corresponding Author: Hisham A. El-Arabaty

Abstract : *This study is aimed at the assessment of realistic values for the modification factors of beams' axial stiffness, applied in finite element analysis of structures under thermal effect. In a previous study, the authors developed an algorithm and software package to determine the relationship between the axial force acting on a specific beam, and the axial stiffness modification factor which takes into consideration the flexural cracking of the beam. In this study, these relationship curves are utilized using a newly developed analytical algorithm for the iterative analysis of RC multistorey frames under the effect of thermal expansion/contraction. A new Excel/Visual Basic software package is developed , and used to control and perform iterative analysis runs on ETABS program, while continually modifying the axial stiffness modification factors of the beams, to reach the accurate value of the modification factors at convergence.*

A group of building frames designed according to the Egyptian code of Practice are used for application of the newly devleoped algorithm and software package, and the effect of different numbers of floors on the axial forces developed in thermal analysis is investigated, with emphasis on estimation of the applicable modification factors in each case. The practical values obtained for these modification factors are compared to the common code specifications, and the common practice in design offices in the Egyptian market. Several gemoetric and section properties of the beam elements in the studied buildings are varied to widen the range of the study, and develop useful recommendations for designers in this field.

Keywords: *Thermal Analysis, Finite Element Modeling, Concrete Cracking, Axial stiffness.*

Date of Submission: 13-02-2019 Date of acceptance: 28-02-2019

I. Introduction

The thermal analysis of multistorey structures has become an integral part of the overall analysis of structures, especially in case of buildings designed to have a high length in one or more directions, without structural gaps.

Reduction of the axial stiffness of floor beams during analysis serves to produce more realistic values of straining actions resulting from thermal analysis. The authors have developed a new analytical algorithm and software package for the estimation of these reduction factors for specified values of axial forces acting on the beams, as outlined in reference [1]. Reference to this software package will be made throughout this paper as "Software Package [I]", to differentiate between it, and between the new "Software Package [II]", which is developed in this study.

The objective of this paper is to incorporate these axial stiffness/axial force variation curves developed in [1], interactively, into the thermal analysis of multistorey buildings. A newly developed algorithm utilizing repeated iterations for the estimation of the reduction factors based on F.E. model results till convergence is used as an accurate technique for the assessment of the most suitable reduction factors for use in multistorey buildings.

II. Existing Literatures and Codes

Various codes of practice have specified certain reduction factors which designers are allowed to use in thermal analysis of structures. This range is very close for the different codes, as **ACI 224.2R-92 (1992) [2], and ACI 349.1R (2007) [3]**, specify a factor of 50%, while the Egyptian Code of Practice **ECP 203 (2017) [4],** allows using a reduction factor of 45%.

M. Mehdi Mirzazadeh, Mark F. Green (2017) [5], Multiple Nonlinear finite element models were performed under the effect of thermal loading and verified against the corresponding experimental results in terms of cracking loads, cracking patterns, ultimate loads, yield loads, and displacements. The validated Nonlinear finite element analysis show that low temperature (down to −40 °C) increases the strength of the beams without stirrups and decreases the number of the cracks on those beams even when temperature differentials are present. On the other hand, the strength and cracking pattern of the beams with stirrups are not affected when exposed to temperatures as low as (−40 °C).

D.R.J.Owen, J.A.Figueiras, F.Damjanic (1983) [6], Describes the implementation of finite element techniques in solving nonlinear concrete problems. Thick plates and shells of reinforced concrete are first considered for which both a perfect and strain-hardening plasticity approach are employed to model the compressive behaviour. A dual standard for cracking and yielding in terms of stresses and strains is considered, which is complemented with a tension cut-off representation. Degenerate thick shell elements using a layered discretisation through the thickness. Also show the importance of inclusion of time effects in the analysis of thermal loading.

Salah E. El-Metwally, Essam H. El-Tayeb, Ahmed M. Yousef (2015) [7], Multiple models have been performed on reinforced concrete flat plates under different thermal loadings, different factors of material nonlinearity, particularly cracking in concrete, have been considered. The results conclude that the major effect of material modelling and including the gravity loads which produce tension stresses in concrete and cracks.

III. Objective of Study

As outlined in detail in reference [1], the authors have developed a novel algorithm for the determination of the cracked axial stiffness of reinforced concrete beams as compared to the uncracked axial stiffness value commonly computed by commercial software package. Reduction factor values are defined as the ratio between the cracked and uncraced axial stiffness values of the beam, and can be used as “input modifiers” to modify the axial stiffness of these beams in a 3-D analysis by a commercial software package.

The software developed by the authors in ref [1] is highly suited for developing an output curve for a beam of given length, section dimensions, and reinforcement, describing the variation of the reduction factors with the value of the axial load acting on the beam. These curves can be developed so as to encompass a wide range of axial force values in order to cover the practical range of values expected in the temperature analysis of a multistorey building.

The main problem facing a researcher or a designer in using the above mentioned curves is the fact that the reduction factor for beam axial stiffness is dependent on the value of the axial force acting on the beam section, which in turn is affected by the reduction factor input into the commercial software package performing the themal analysis.

In order to address the above problem, an iterative approach is therefore required in order to repeatedly compute the axial stiffness reduction factor, and use it in the 3-D analysis of the multistorey building, and consequently obtaining the resulting axial force in the beam and re-using it to re-compute the reduction factor. Repetition of these iterations till convergence can produce accurate values for the reduction factors, which correspond to the practical case of “cracked section” beams, in thermal analysis.

The resulting axial stiffness/axial force variation curves obtained from Software Package [I] accurately describe the expected behavior of these beams under axial loads, while taking into consideration the beams’ bending cracks. A new program is developed in this study to use these curves in an iterative analysis. The new program (Software Package [II]), is developed using VISUAL BASIC, and includes a special routine for controling the input, output and runs of ETABS software. Details of the analytical alogrithm upon which the new software package is bases are shown in the next section.

IV. Analytical Algorithm

The approach adopted here for performing the analysis is an iterative analysis procedure, which is presented in the flowchart in Figure (1), and can be summarized as follows:

1. Full design of each building frame according to the Egyptian Code of Practice under vertical and lateral loads. ETABS software package is utilized.
2. The design results are used to develop the final section properties for both columns and beams to be incorporated into the 3 models for thermal analysis.
3. A link between the developed software package (1), and ETABS software is developed using VBA.
4. Initial reduction factors for both tension and compression are assumed as (1.00) for the initial thermal analysis. This corresponds to the case of full un-cracked axial stiffness for the beams.
5. Temperature load values are applied for both expansion and contraction cases, according to the Egyptian Code.
6. ETABS software is used for the analysis, and the resulting axial forces in the beams are determined, and input back into the developed software package (1).

7. Actual values for the axial stiffness reduction factors are obtained, and input back into the ETABS model, to modify the axial stiffness of the beams.
8. Several iterations of steps (5, 6&7) are repeated, till convergence is reached. The analysis is assumed to reach convergence, when the difference between the reduction factors obtained in 2 successive iterations is less than 1% of the reduction factor value.
9. Once convergence is reached, final results are determined for the building under study.
10. The same procedure is applied for the other buildings.

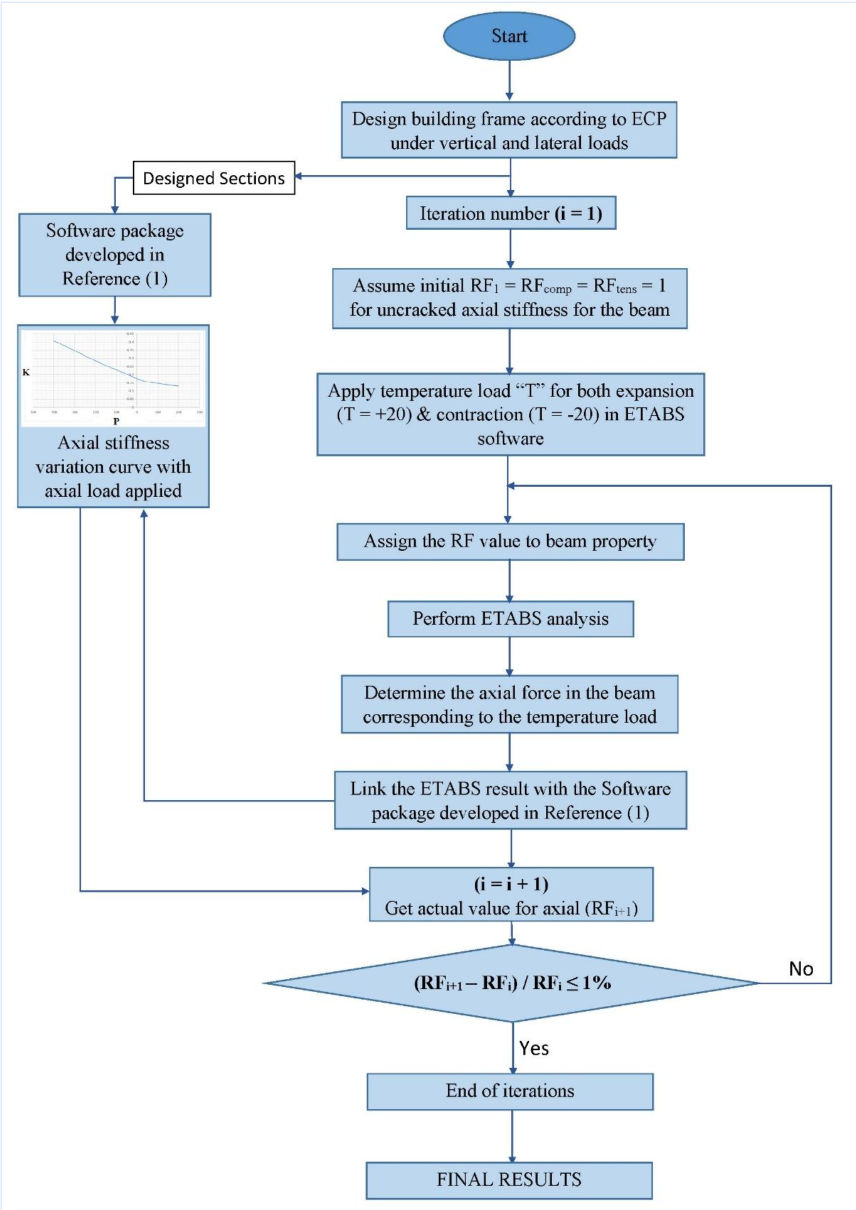


Figure 1. Flowchart for the iterative computation of applicable modifiers for beams' axial stiffness coefficients in multistorey building analysis

Software Package [II] is developed using VISUAL BASIC, to perform the step by step procedure shown in Figure (1). The new program includes a highly sophisticated special routine for controling the input, output and runs of ETABS software.

V. Selection of Analysis Cases

The structures selected for this study are typical building frames. A number of frames were selected for thermal analysis, with emphasis on taking into consideration the effect of flexural cracking of the beams on the overall behavior of the building.

The selected building frames are shown in Figure (2), and are described in Table (1). Each frame is analyzed under the effect of vertical and lateral loads (Wind and Earthquake), and the columns and beams are designed according to the Egyptian Code of Practice. The models used for the 3 buildings therefore represent practical cases for actual buildings.

The number of Storeys was varied as 12, 8 and 4 Storeys for the 3 buildings A, B & C respectively. Choice of the "Number of Storeys" parameter here is based on its effect on the thermal analysis results. The variation of number of Storeys results in different vertical and lateral loads on the columns, and thus the column sizes at the base are drastically different for the case of each building. This variation in column inertias at the base, allows for the investigation of a wide range of practical values for the columns sizes (as compared to the frame beams), and for their restraining effect on the beams' expansion/contraction.

Case No.	Span Length (mm)	Section Dimensions (mm)	Steel Reinforcement Area = As (mm^2)	Number of Storeys
1A	6000	250x700	800	12
1B				8
1C				4
2A	6000	250x900	750	12
2B				8
2C				4
3A	7500	250x900	1100	12
3B				8
3C				4
4A	9000	250x900	1500	12
4B				8
4C				4
5A	6000	250x700	1050	12
5B				8
5C				4

Table 1. Beam data and number of storeys of different analysis models

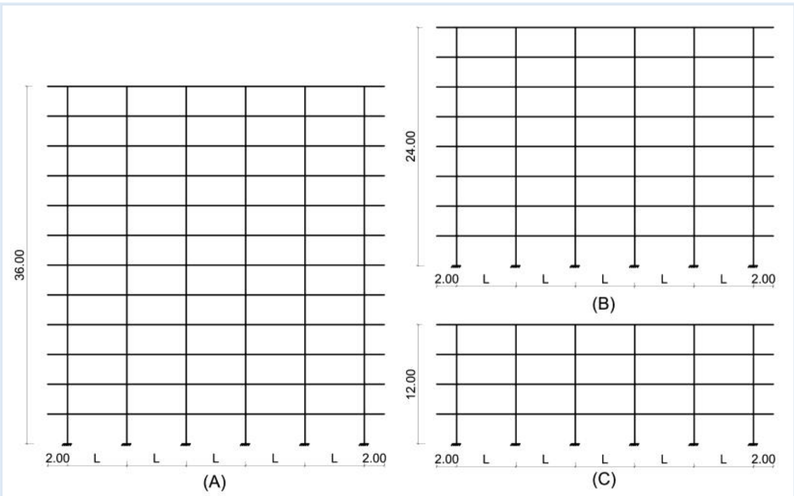


Figure 2. Layout of RC frames for 3 multistory buildings
a) 12 Storeys b) 8 Storeys c) 4 Storeys

VI. Iterative Analysis of Model 1

In this section, the detailed procedure, and intermediate steps performed in a typical analysis run using the developed software are outlined. For Model 1, the basic relationship between axial forces acting on the beam and the equivalent "cracked axial stiffness" of the beam is established using software package [I]. This relationship is shown in Figures (3) & (4). Figure (3) illustrates the effect of bending cracks on the beam's axial behavior, where the value of the beam axial displacement rises with an increasing rate as the tensile axial force increases, and goes down more rapidly as the axial load increases on the compression side. The equivalent stiffness is computed based on secant approach, and plotted in Figure (4), as a percentage of the full section axial compressive stiffness (EA/L).

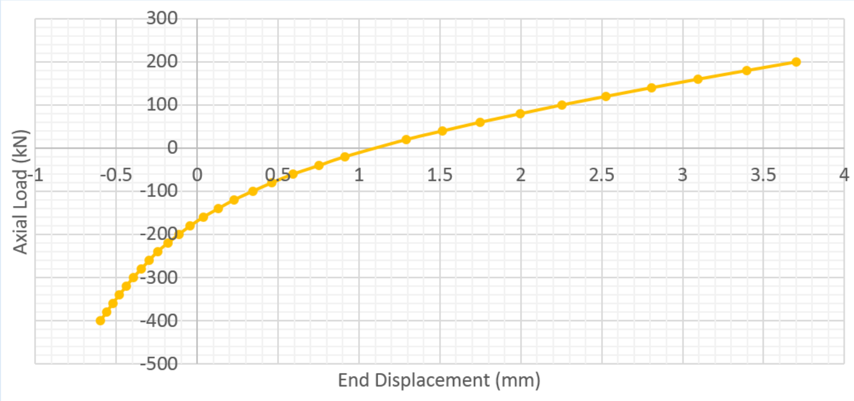


Figure 3. Force-displacement curve for beam in axial direction (Models 1A, 1B & 1C)

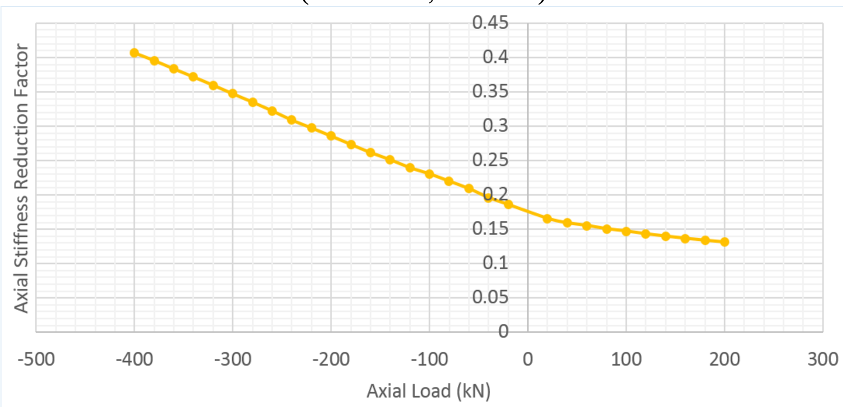


Figure 4. Force-Reduction factor curve for beam in axial direction (Models 1A, 1B & 1C)

For the thermal expansion case, the temperature variation of 20 degrees celsius is input into the etabs model, as a thermal load case. Applying the procedure outlined in section (IV), using software package [II], the ETABS analysis run is performed repeatedly, while the value of the reduction factor is computed and re-entered into the analysis in each iteration. The same procedure is repeated for the tension (contraction) case, and the results of both cases are shown in Table (2).

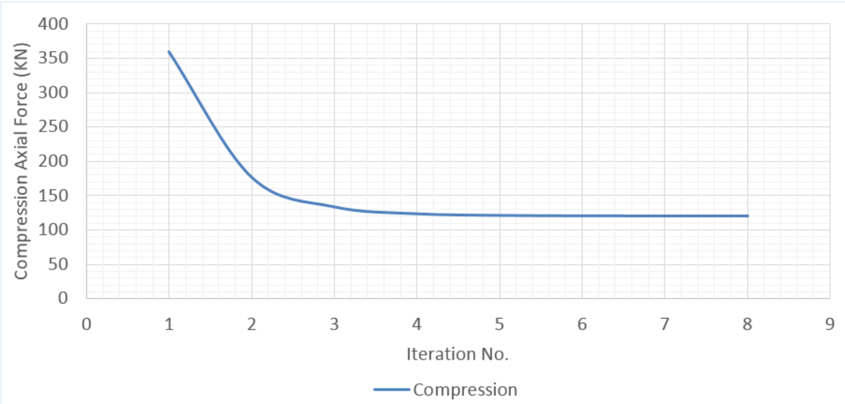
Iteration No.	12 Storeys building – Ground floor beam	12 Storeys building – Ground floor beam
	Axial Force (kN)	Axial Force (kN)
	Compression	Tension
1	359	125
2	177	77
3	134	82
4	124	81
5	121	81
6	121	81
7	120	81
8	120	81

Table 2. Beams' axial forces resulting from iterative analysis under thermal Expansion/Contraction for 12-Storeys building (Model 1A)

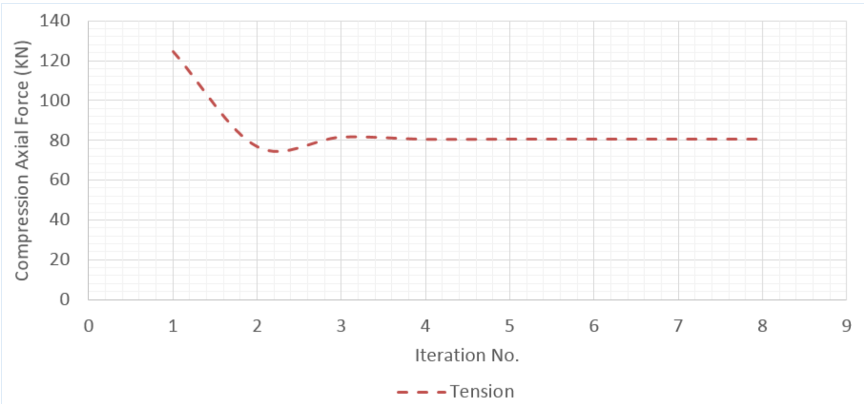
The reduction factors are computed as the ratio between the cracked stiffness, and the uncracked full section stiffness, and are shown in Table (3). The variation of the axial force in the beam with the number of iterations is shown in Figure (5) for the compression and tension cases respectively, while the variation of the reduction factors with the number of iterations is shown in Figures (6) for the compression and tension cases respectively.

Iteration No.	12 Storeys building – Ground floor beam	12 Storeys building – Ground floor beam
	Axial Modifier (RF_{comp})	Axial Modifier (RF_{tens})
	Beam Expansion [Compression]	Beam Contraction [Tension]
1	1.000	0.250
2	0.383	0.142
3	0.272	0.152
4	0.247	0.150
5	0.242	0.150
6	0.240	0.150
7	0.240	0.150
8	0.240	0.150

Table 3. Beams' axial force reduction factors under thermal expansion/contraction For 12-Storeys building (Model 1A)

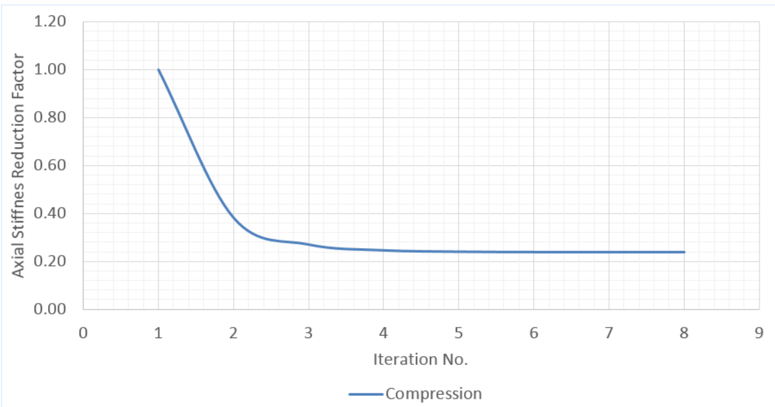


a. Case of thermal expansion

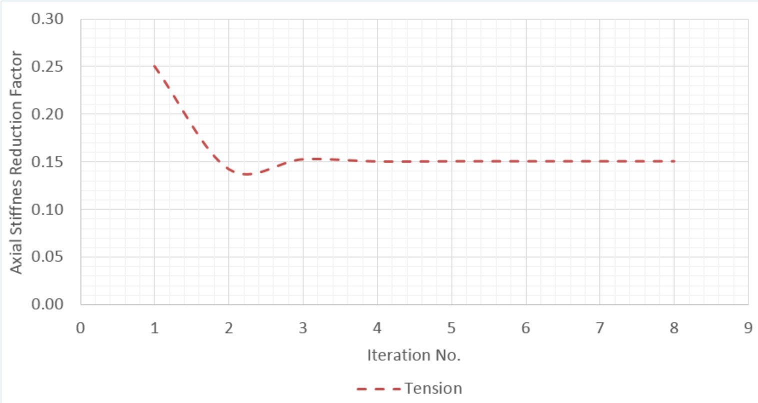


b. Case of thermal contraction

Figure 5. Variation of axial force with iteration number till convergence



a. Case of thermal expansion



b. Case of thermal contraction

Figure 6. Variation of axial stiffness reduction factors with iteration number till convergence

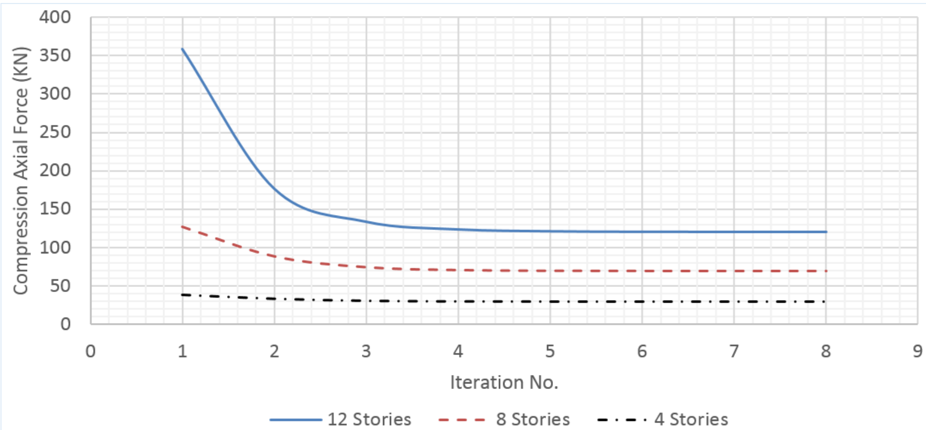
From Figures (5) & (6), it can be seen clearly that the initial assumption of full section axial stiffness (RF = 1) is very high compared to the final results obtained, where the actual reduction factors corresponding to the level of cracking in the beam is 0.24, and 0.15 for the expansion and contraction cases respectively. These values are also far lower than the (50%) factor recommended by some codes of practice, and used by designers widely in the commercial market in Egypt.

Another important observation from the Figures, is the effect of this reduction in axial stiffness on the axial load. ETABS analysis produced a compressive axial force of 359 kN in the ground floor beam for the initial case using full section uncracked axial stiffness for the beams. The same model produced a much reduced value of 120 kN for the final case, where the accurate reduction factor is applied, thus a 67% reduction in compressive axial force value is obtained by applying the axial stiffness reduction factors to the analysis. A similar reduction in axial force from 125 kN to 81 kN (35%) can be seen for the tension case.

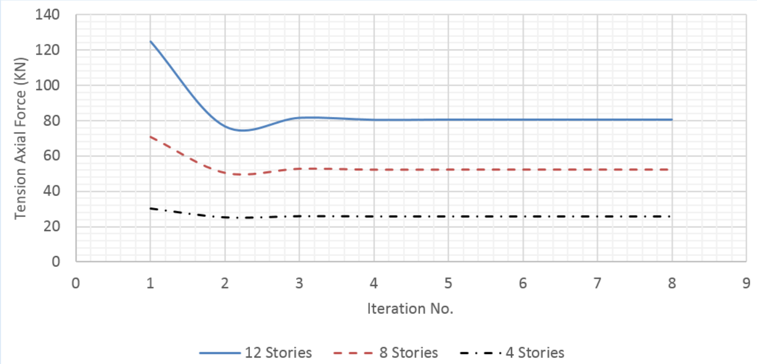
VII. Effect of Building Number of Storeys

While the number of storeys does not affect the behavior of a specific floor in expansion, the building height, number of storeys, and the resulting column loads do affect the design of the columns and thus the size of the column sections. Larger column sections produce a higher column inertia, which provides higher restraint for the beams expansion/contraction. In this section, this effect is investigated through the analysis of the 3 buildings in Figure (2). Analysis runs are performed for Models 1A, 1B & 1C, for both compression and tension cases.

Figure (7) shows the variation of axial force with the number of iterations for the compression and tension cases for the 3 buildings, respectively. The stiffness reduction factors are computed and plotted against the number of iterations in Figure (8). Summary of the final axial forces obtained after convergence, and the final stiffness reduction factors for all 6 cases are illustrated in Figures (9) & (10) respectively.

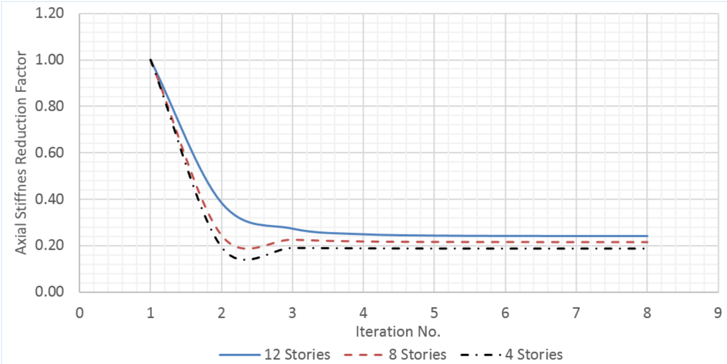


a. Case of thermal expansion

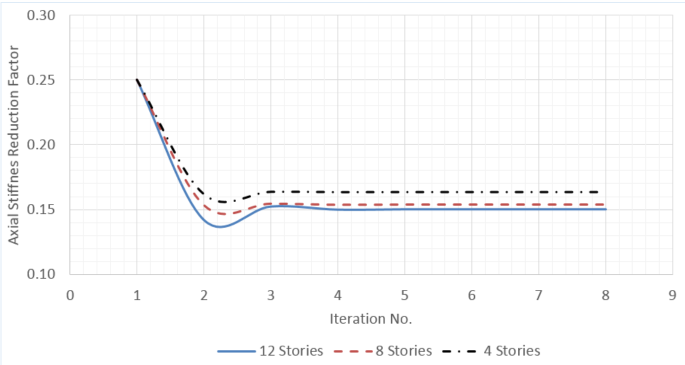


b. Case of thermal contraction

Figure 7. Variation of axial force with iteration number for buildings of different numbers of storeys



a. Case of thermal expansion



b. Case of thermal contraction

Figure 8. Variation of axial stiffness reduction factors with iteration number for buildings of different numbers of storeys

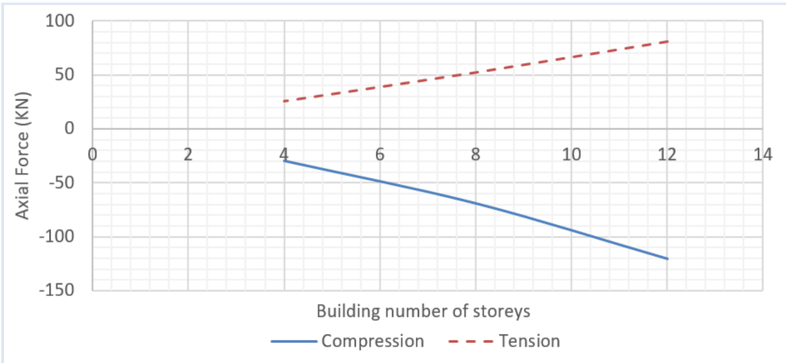


Figure 9. Final axial force values after convergence
For Models 1A, 1B & 1C for expansion and contraction cases

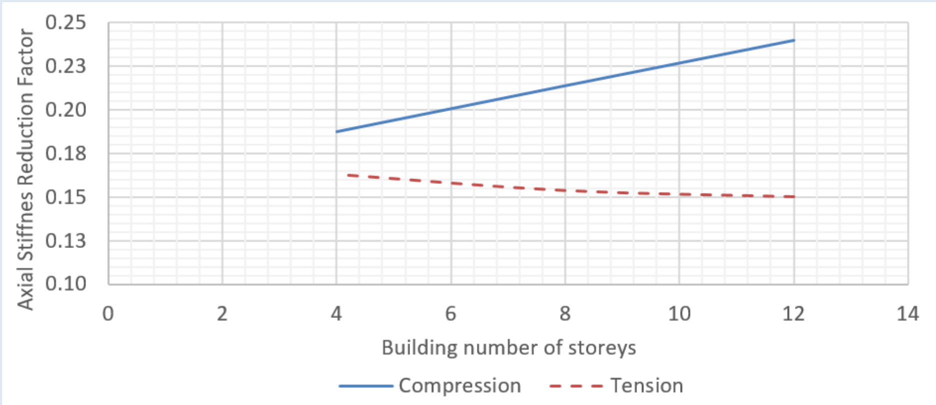


Figure 10. Final axial stiffness reduction factors after convergence For Models 1A, 1B & 1C for expansion and contraction cases

From the figures, it can be seen that both the axial force and the reduction factor (RF) for the compression case is higher for the 12 storeys building, than the 8 storeys building, which in turn has a higher RF value than the 4 storeys building. This can be explained by the increased columns rigidity for the higher buildings, which produces higher axial forces in the beams. The overall range of compression reduction factors for the 3 buildings is between 0.18 and 0.24, which is quite low as compared to the commonly used 50% factor.

The tension case (contraction) produced lower reduction factors ranging from 0.15 to 0.17. This can be explained by the fact that the tension case increases the beam cracking, and therefore reduces its axial stiffness as compared to the uncracked axial stiffness value. These low figures indicate that using the 50% factor to modify the axial stiffness of beams in a thermal analysis of similar frames can produce unrealistically high values for the axial forces in the beams, and consequently exaggerate the corresponding values of bending moments, shear forces, and stresses resulting in the building columns.

VIII. Parametric Study

The effect of different variables on the resulting stiffness reduction factors is investigated through a number of analysis runs. The results shown in this section are the final values of axial force and axial stiffness reduction factors obtained from the different iterative analysis runs after convergence.

The effect of steel reinforcement area can be seen by comparison of results of run cases 1 & 5, where all input parameters were kept the same except for increase of the beam steel area by 30% for case 5. The results are illustrated in Tables (4) & (5), and are shown in Figures (11) & (12) for the compression and tension cases respectively.

	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	120	69	30
Case 5	157	82	32

a. Final compressive axial forces in ground floor beams

	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	0.240	0.214	0.188
Case 5	0.330	0.282	0.250

b. Final compressive axial stiffness reduction factors in ground floor beams

Table 4. Comparison of analysis results for Cases 1 & 5 under thermal expansion after convergence

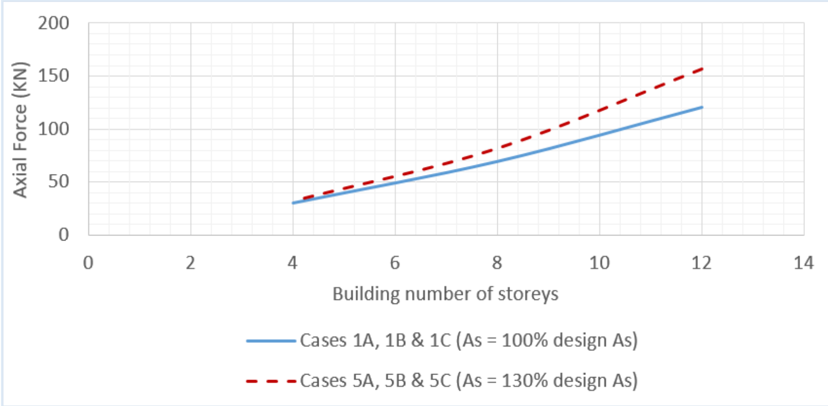
	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	82	52	26
Case 5	142	82	43

a. Final tensile axial forces in ground floor beams

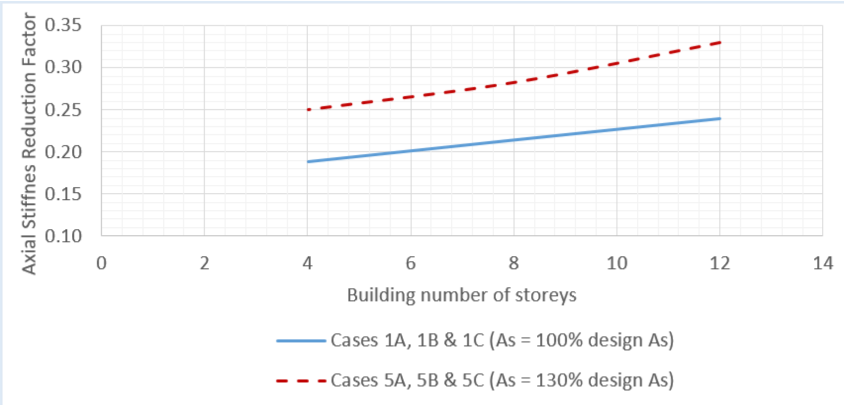
	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	0.150	0.154	0.163
Case 5	0.292	0.308	0.327

b. Final tensile axial stiffness reduction factors in ground floor beams

Table 5. Comparison of analysis results for Cases 1 & 5 under thermal contraction after convergence

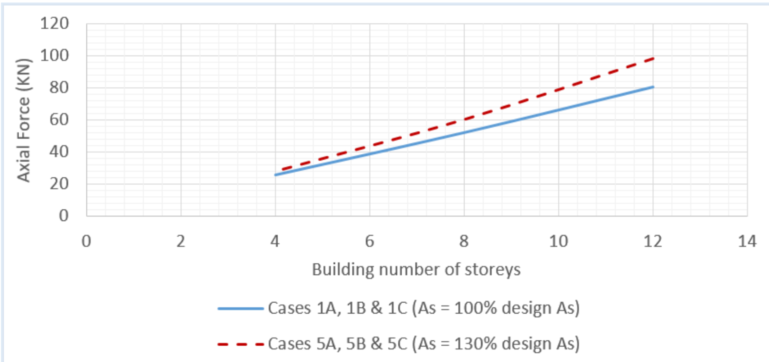


a. Final axial force values after convergence

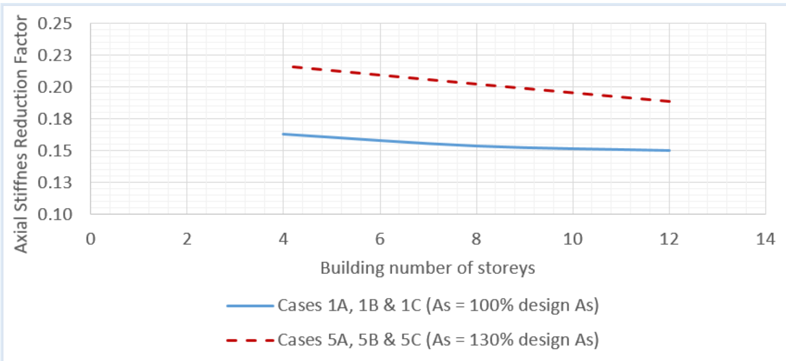


b. Final axial stiffness reduction factors after convergence

Figure 11. Effect of steel reinforcement amount (Thermal expansion case)



a. Final axial force values after convergence



b. Final axial stiffness reduction factors after convergence

Figure 12. Effect of steel reinforcement amount (Thermal contraction case)

From the results, it can be seen that the amount of steel reinforcement in the beam has a significant effect on the beams' axial stiffness, and consequently on the resulting axial forces in the beams. Both compression and tension RFs have increased with the increase of steel reinforcement area. This can be explained by the reduced level of cracking, and crack widths produced by the increase in steel area.

Different beam spans (6, 7.5 & 9 m) are used for analysis runs 2, 3 & 4 respectively. The comparison of results is used for investigation of the effect of change of span length on the beams' axial stiffness. It is to be noted that for every span, the beams are designed according to the Egyptian code of practice, and thus have different steel reinforcement areas, as shown in Table (1). The concrete section dimensions is kept the same (250x900) for all analysis runs.

The results are illustrated in Tables (6) & (7), and shown in Figures (13) & (14) for the compression and tension cases respectively.

	12-Storeys building	8-Storeys building	4-Storeys building
Case 2	129	74	31
Case 3	170	94	47
Case 4	191	99	42

a. Final compressive axial forces in ground floor beams

	12-Storeys building	8-Storeys building	4-Storeys building
Case 2	0.201	0.170	0.148
Case 3	0.284	0.241	0.215
Case 4	0.337	0.301	0.275

b. Final compressive axial stiffness reduction factors in ground floor beams

Table 6. Effect of steel reinforcement amount (Thermal expansion case)

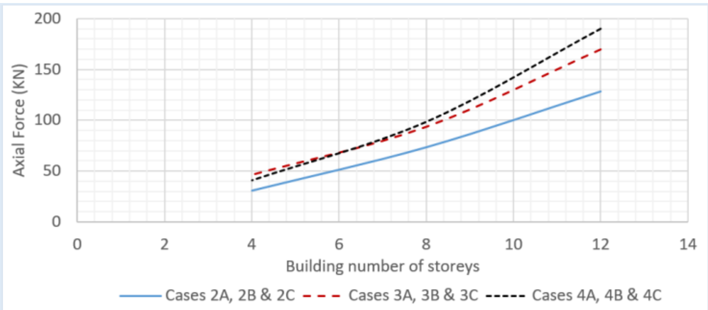
	12-Storeys building	8-Storeys building	4-Storeys building
Case 2	77	52	26
Case 4	106	68	39
Case 5	134	79	37

a. Final tensile axial forces in ground floor beams after convergence

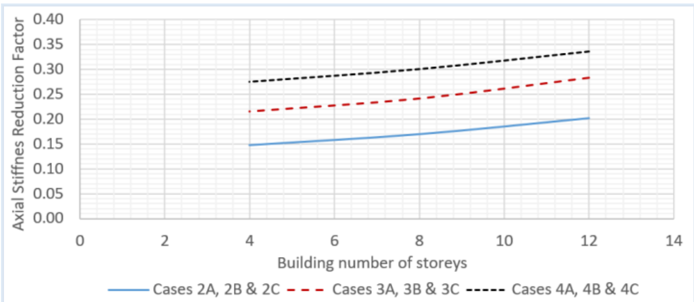
	12-Storeys building	8-Storeys building	4-Storeys building
Case 2	0.111	0.112	0.127
Case 4	0.160	0.166	0.177
Case 5	0.217	0.232	0.240

b. Final tensile axial stiffness reduction factors in ground floor beams

Table 7. Effect of steel reinforcement amount (Thermal contraction case)

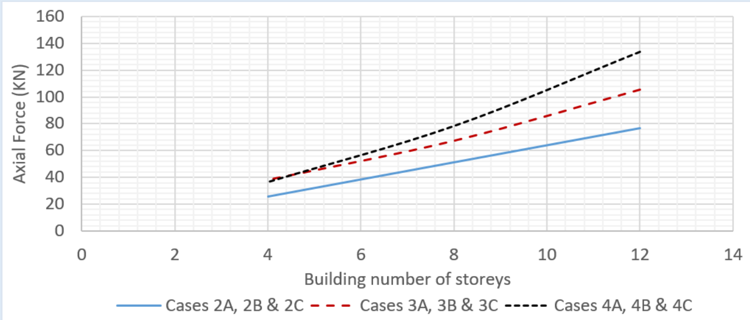


a. Final axial force values after convergence

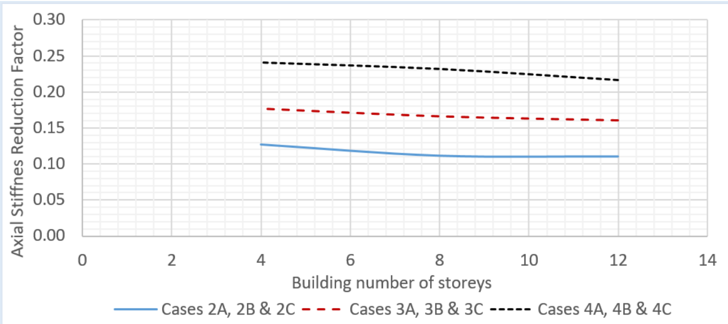


b. Final axial stiffness reduction factors after convergence

Figure 13. Effect of span length (Thermal expansion case)



a. Final axial force values after convergence



b. Final axial stiffness reduction factors after convergence

Figure 14. Effect of span length (Thermal contraction case)

It can be seen that increase of span length has the effect of producing higher RF values in both cases of tension and compression. While the higher span length is expected to increase the beam cracking, the effect of the increased reinforcement in the longer beams is to increase the cracked axial stiffness of the beam. The overall range of RF values obtained in both compression and tension are still within the 33% range for the expansion (compression) case, and the 25% range for the contraction (tension) case.

For all span lengths, the 12 storeys building analysis produced higher RF values, and higher axial force values than the 8 and 4 storeys buildings. This effect is far more pronounced for the case of the longer spans, as can be seen in the high rate of increase in axial force value for the 9m span length shown in Figures (13a) and (14a).

The effect of section dimensions is illustrated by comparison of results of cases 1 & 2, where all input parameters are kept the same except for increase of the beam dimensions from 25 x 70 cm to 25 x 90 cm, while keeping the steel area almost the same. The results are illustrated in Tables (8) & (9), and shown in Figures (15) & (16) for the compression and tension cases respectively.

	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	121	70	30
Case 2	129	74	31

a. Final compressive axial forces in ground floor beams

	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	0.240	0.214	0.188
Case 2	0.201	0.170	0.148

b. Final compressive axial stiffness reduction factors in ground floor beams

Table 8. Effect of section dimensions (Thermal expansion case)

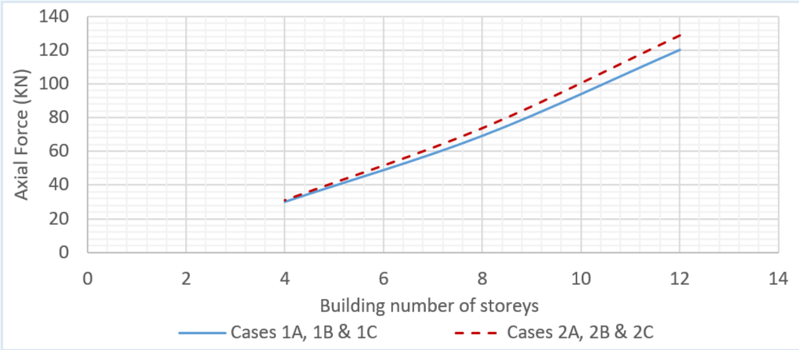
	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	81	53	26
Case 2	77	52	26

a. Final tensile axial forces in ground floor beams

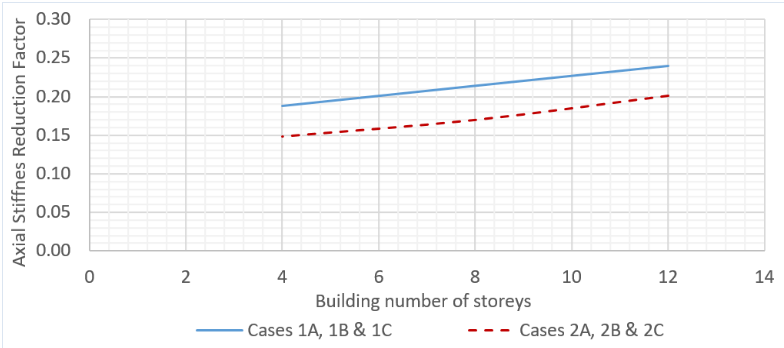
	12-Storeys building	8-Storeys building	4-Storeys building
Case 1	0.150	0.154	0.163
Case 2	0.111	0.112	0.127

b. Final tensile axial stiffness reduction factors in ground floor beams

Table 9. Effect of section dimensions (Thermal contraction case)

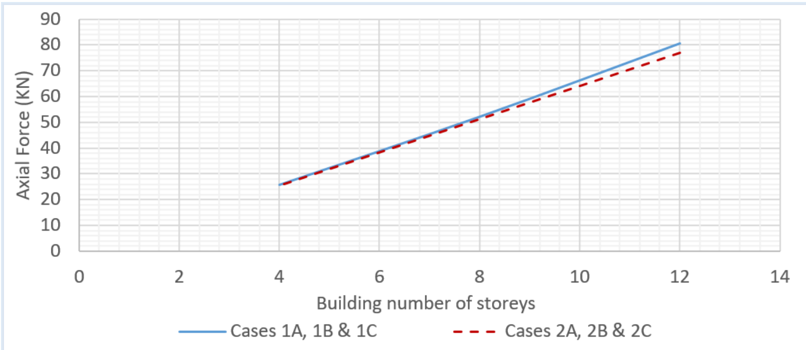


a. Final axial force values after convergence

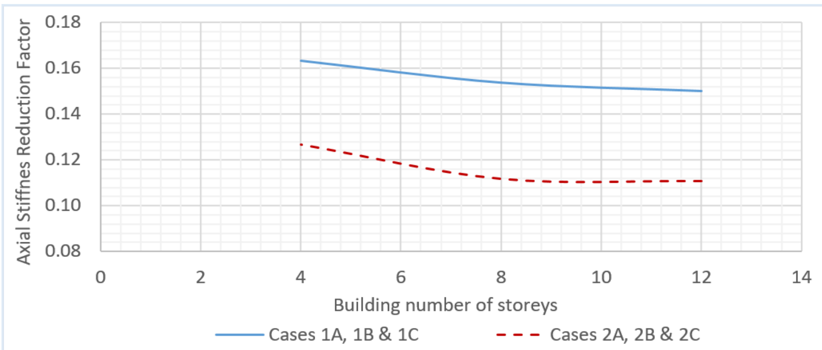


b. Final axial stiffness reduction factors after convergence

Figure 15. Effect of section dimensions (Thermal expansion case)



a. Final axial force values after convergence



b. Final axial stiffness reduction factors after convergence

Figure 16. Effect of section dimensions (Thermal contraction case)

A very interesting observation can be made from the results in Tables (8) & (9), and Figures (15) & (16). While the RF values are affected by the change in section dimensions, it is noted clearly that the final axial forces obtained in the ground floor beams are almost identical (with minor variations) for the compression and tension cases, regardless of the section size. This indicates that the governing factor in determining the axial forces in the beams is the steel reinforcement amount, and not the concrete section dimensions.

IX. Summary and Conclusions

In this research, a number of actual building frames of various heights were designed according to the Egyptian Code of Practice, and used for practical application of a newly developed algorithm to perform thermal analysis of the buildings.

The developed algorithm applied into a new software package is based on iteratively running ETABS program repeatedly, using the resulting axial force values in the beams to determine the appropriate reduction factor for the beams' axial stiffness, and feeding back the value of this factor into ETABS, and repeating the runs until convergence. The developed algorithm was found to be a very powerful tool for the accurate determination of the final modification factors, and axial force values. Convergence was usually reached within 10 iterations or less.

While several particular results pertaining to the specific results are discussed in detail in the previous sections, the analysis results obtained for the selected cases of building frames designed according to the Egyptian Code of Practice, indicate that the 45 to 50 % stiffness reduction factors specified in the various codes is quite high compared to the actual range of values, which is generally less than 35% for the compression case (thermal expansion), and less than 25% for the tension case (thermal contraction).

Analysis results showed that the appropriate reduction factors to be applied in a thermal finite element analysis of a framed structure to account for the beams' flexural cracking depend strongly on the building's number of storeys. The increase in column dimensions caused by the increase in column axial loads produces a higher restraining effect on the beams' expansion/contraction.

While the range of building heights (4, 8 & 12 storeys) studied in this research produced reduction factors less than those specified by the different codes, it is highly recommended that today with the sharp rise in height of buildings being constructed in Egypt, buildings with a higher number of floors should be studied carefully to determine the appropriate reduction factors, in order not to underestimate the effect of thermal expansion/contraction on the columns sideways movements, and corresponding straining actions.

Amount of steel reinforcement in the beams was also found to have a significant effect on the reduction factors, where increasing the percentage of steel rft in the section rapidly increased the values of the reduction factors, and thus produced a considerable increase in the final axial forces recorded in the beams.

A common practice in the engineering community is to increase both top and bottom steel rft of beams significantly, in cases where limitations are imposed on the concrete section dimensions. Based on the results of this study, such practice will be accompanied by higher values for the axial stiffness reduction factors, and consequently, higher values for the final axial forces produced by the thermal effect. This phenomenon should also be taken into consideration by designers.

In cases of very tall buildings, and where beams reinforcement are significantly higher than the normal design practice, based on the results of this study, it is highly recommended that the code specifications be updated to require designers to perform a nonlinear analysis to determine the appropriate axial stiffness reduction factors, or if this analysis is not performed, to reduce the allowable reduction, or eliminate it altogether in such cases.

References

[1]. Hisham A. El-Arabaty, Gamal H. Mahmoud, Nasr E. Nasr, Mohamed A. Abdul Rahim, Finite Element Modelling of Structures Subjected to Thermal Loading, *IOSR-JMCE Journal, vol. 15, no. 6, 2018, pp. 31-43.*

[2]. ACI Committee 224.2R-92, Cracking of Concrete Members in Direct Tension, *ACI Structural Journal, 1992, pp. 6:7.*

[3]. ACI Committee 349.1R-07, Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures, *ACI Structural Journal, 2007, pp.4.*

[4]. ECP 203 (2017), Design & Construction of concrete structures, *HBRC Journal, 2017, pp. 6-22.*

[5]. M. Mehdi Mirzazadeh, Mark F. Green, Non-linear finite element analysis of reinforced concrete beams with temperature differentials, *ELSEVIER Journal, 2017, Volume 152, Pages 920-933*.

[6]. D.R.J.Owen, J.A.Figueiras, F.Damjanic, Finite element analysis of reinforced and prestressed concrete structures including thermal loading, *ELSEVIER Journal, 1983, Volume 41, Issue 3, Pages 323-366.*

[7]. Salah E. El-Metwally, Essam H. El-Tayeb, Ahmed M. Yousef, Analysis of RC Flat Slab System for Thermal Loads, *IJEIT Journal, 2015, Volume 4, Issue 12.*

Hisham A. El-Arabaty. "Interactive Implementation of Axial Stiffness Reduction Factors in Thermal Analysis of Multistory Buildings." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 1, 2019, pp. 22-35